ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

VOLUME XI January 1952 NUMBER 41

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The accessibility of knowledge, II

In an earlier issue (9, 53, 1950) we discussed the difficulties facing the modern research worker in his attempts to collect information on work previously done, and to keep abreast of developments, in his particular sphere of interest. We shall here consider some of the means which have been devised to guide him to the sources of the information he is seeking.

As the inquirer turns to the library, he is confronted with a bewildering mass of books and periodicals. It is obvious that the books must be arranged in some systematic way; they must be classified. Early attempts at classification of objects in a collection may be traced back to antiquity. As far as books are concerned, the problem became increasingly important with the advent of printing and the concomitant extension of libraries, but it was not until about the middle of the nineteenth century that complete cataloguing of large libraries was undertaken.

Leaving aside the usual author index, which is arranged alphabetically, classification according to subject involves some system of labelling the books in such a way that they can be easily arranged in a certain defined sequence, and that any book on a given subject can be easily found. When we speak of arranging the books, we really refer to the counterparts of the books: the cards in the index which forms the working catalogue of the library.

The correct labelling of a book is an expert's job and the symbol used should thus be as brief as possible. The arrangement of the labelled books should be a simple mechanical process which can be entrusted to clerical staff. The correct sequence of the symbols should therefore be easily recognizable without reference to a special code. Works on related subjects should be placed close together.

It is obvious that the title of a book, or a word or combination of words from the title, does not afford any adequate symbol for a classification of a large collection of works on different subjects. The title is seldom a complete, and is often hardly a clear, indication of the subject matter. There is, further, a disconcerting choice of key words and combinations of key words. The only easily recognizable sequence of words is alphabetical, but an alphabetical arrangement would separate works on similar subjects; it is also confused by uncertainty in the use of synonyms, and by the fact that the same word is used in different subjects with different meanings: thus there are 'cells' in biology and in the theory of groups, and 'fibres' in textiles and in the nervous system. If the collection contains works in various languages, names of main subjects may be spelt differently, and the sequence of card indexes would be different in different languages. Even chemistry becomes *chimica* in Italian, *química* in Spanish, and *kemi* in Danish. We may discard the use of words as symbols in classification:

'Words are like leaves, and where they most abound
Much fruit of sense beneath is rarely found.'

In 1873 Melvil Dewey invented his 'decimal classification and relativ index,' the first edition of which was published in 1876. In this system the whole of knowledge is conceived as unity, and the symbols representing the various subjects are decimal fractions. The sequence is purely numerical and, Arabic numerals and decimal fractions being independent of language and being used as symbols for concepts, not words, the system is of universal application. In 1895 an international conference on bibliography was convened in Brussels, on the initiative of Paul Otlet and Henri La Fontaine. Out of the deliberations arose what is now the International Federation for Documentation. The conference decided to adopt the main structure of the Dewey decimal classification, and to develop it according to the needs of the steadily increasing bulk of bibliographic material. In the following years, national sections were established, first in Holland, and later in America, Belgium, Denmark, France, Germany, Great Britain, Italy, Spain, Sweden, and Switzerland. The development of the classification is in the hands of a large number of national committees of experts in the various subjects, with a central secretariat at The Hague. Notes on extensions proposed are circulated to all members and, if adopted, are incorporated in subsequent publications of the tables. International congresses are held from time to time for the discussion of major alterations; the last one took place in Rome in September 1951. Sections of the tables are now available in English, French, German, Italian, Spanish, and Swedish. When the full tables are available, they will constitute a unique and reliable universal dictionary of technical

terms. The classification is in use in thousands of libraries, information bureaux, professional institutions, research institutes, government offices, and manufacturing concerns.

The divisions of the 'unity' of knowledge are:

.0 General. Bibliography. Libraries. Corporate bodies.
.1 Philosophy.
.2 Religion.
.3 Social sciences.
.4 Philology.
.5 Pure science.
.6 Applied science. Medicine.
.7 Art.
.8 Literature.
.9 History. Geography. Biography.

Each section is subdivided by adding decimals, proceeding from general to more specialized subjects:

.5 Pure science.
.58 Botany.
.581 General botany.
.581.1 Plant physiology.
.581.11 Circulation. Absorption.
.581.113 Exudation of water.

In practice, the first decimal point is omitted, but it is essential that it should remain imprinted on the reader's mind, remembering that 581 (meaning .581) precedes 59 (meaning .59) in numerical ascending order. The point after 581 is used as an aid to memory, and to emphasize certain subdivisions.

It is not often that the contents of a book or an article can be exhaustively indicated by a single number. In the case of two or more related subjects, the separate numbers are given, linked by the colon sign. Thus:

547 Organic chemistry.
547.97 Colouring matter
581.19 Chemical constituents of plants.
547.97:581.19 Organic colouring matter of plants.

The same expedient is used where a subject is of interest to workers in two different fields, such as botany and agriculture. When two or more numbers are used, the work must be entered under each number.

There are also a number of analytical subdivisions which can be attached to the numbers in certain sections, and, further, means of indicating the point of view, the form, etc.

A necessary adjunct to the tables of the classification is an alphabetical index to guide the inexperienced reader to the proper numbers for the subject in which he is interested. The word entries should comprise all the concepts classified, including synonyms, and should allow, by suitable sub-entries, for different uses of the same word.

The decennial index of ENDEAVOUR, 1942–51, was published with the October issue and contains a subject index arranged according to the decimal classification.

In the alphabetical key an attempt has been made to collect all the significant descriptive words that might occur to a reader who wishes to consult an article more or less vaguely remembered, in addition to those indicating the concepts of the classification tables. The numerical entry gives the number in the subject index under which articles on this and related subjects are found.

There are, of course, numerous other classification systems, some developed for a more specialized group of subjects, and it has never been seriously claimed that the universal decimal classification is the best possible. It is just one of many good systems, all of which have their faults.

When we come to the second difficulty mentioned above, that of keeping abreast of recent developments in a certain subject, the first obstacle is the time-lag between a completed research and the publication of the report. Even when the report is published it may not be easy to locate. It is reckoned that upwards of 750,000 papers are published annually on scientific and technical subjects, and these are distributed over about 15,000 important periodicals. Some of these periodicals are devoted mainly to a specific subject; some are of a more varied content. Even the specialized journals often contain articles of interest to research workers in a field apparently remote. It seems that, at present, only about half the published articles are abstracted by the various abstracting services. The remedy might be a central indexing bureau, but its realization seems far away. Careful indexing by each journal of its own published articles, on some universally known classification system, would make the scrutiny of journals easier, and would help abstracting services in their selection of articles, enable them to extend the range of journals covered, and contribute towards the reduction of the second time-lag, namely that between the publication of a paper and the appearance of the abstract.

Some recent advances in chromatography

ARNE TISELIUS

It is rare for a single new technique to advance almost every part of a major field of science. This distinction may, however, be justly claimed for chromatography, for there is scarcely any branch of chemistry in which it has not already been profitably applied, and its possibilities are still very far from being exhausted. In this article a leading exponent of the method discusses the underlying principles. Particular stress is laid on the various methods of developing chromatograms, the relative merits of which are often only imperfectly appreciated.

Methods of separating substances are of basic importance for chemistry as a whole, not only for preparative and analytical work in a narrow sense, but for the fundamental conceptions of chemical individuality, particularly in research on products isolated from living organisms.

In these days, when chemists have become accustomed to the necessity of using complicated apparatus to achieve the highest refinements in their operations, it is interesting that some methods are available which, though of great simplicity, nevertheless show an amazingly high efficiency and specificity. Chromatographic analysis is such a method; it has made possible important advances in bio-chemistry and organic and nuclear chemistry, and seems to provide the key to a number of problems of the greatest current interest. The name chromatography—implying a restriction to coloured substances—is of historical significance, but bears little relationship to the way in which the method is applied today.

Pioneer experiments were performed by the botanist Mikhail Tswett, and were published in his book *Chromophylls in the Plant and Animal World* (Warsaw, 1906). Tswett is generally regarded as the inventor of adsorption chromatography, but it has lately been pointed out that as early as 1897 the American chemist D. T. Day published some interesting observations on the purification of crude petroleum by filtration through a column of powdered limestone, and later succeeded in isolating different fractions in this way. Following Day, the German chemists Engler and Albrecht made use of a similar procedure for fractionating mixtures of hydrocarbons and other substances. Russian petroleum chemists also employed the method before Tswett. It is not known, however, if this earlier work influenced Tswett in his first chromatographic experiments.[1]

Tswett's classical experiment was made as follows. A petroleum ether extract of green leaves was poured on to a column of finely powdered calcium carbonate, and was followed by a quantity of the pure solvent. Tswett observed that the pigment, originally retained at the top of the column, was split up into a number of zones, which migrated at different rates down the column as the solvent percolated through it. This process of separation of the zones due to their different rates of movement is known as development. He observed successively a slowly moving, pale yellow zone, two green, and three yellow zones. In this way the composite nature of chlorophyll was proved, and a convenient way of isolating the components was established. Tswett's method is shown diagrammatically in figure 1. This experiment demonstrates the simplicity of the method and its great specificity, for we now know that chlorophylls *a* and *b*, separated by Tswett, differ only in the replacement of a CH_3— group in one by a —CHO group in the other.

The method was almost forgotten for about thirty years. It was not until 1931, through the work of Kuhn, Winterstein, and Lederer [1] on the separation of carotenoids, that the method was revived, or, one might even say, rediscovered. These authors used essentially the same arrangement as Tswett, and a large amount of work, yielding important results, has been done and is being done in this simple way, generally making use of organic solvents. The possibility of following the development of chromatograms containing colourless substances—for example, by using their fluorescence in ultraviolet light to locate the zones—was soon realized. There is hardly any class of organic substance which does not lend itself to more or less complete separation in this

[1] For a recent discussion of the history of chromatography the reader is referred to interesting contributions by H. Weil and T. I. Williams, *Nature*, **166**, 1000, 1950; **167**, 906, 1951.

way. Carotenoids and other natural pigments present particularly beautiful examples of the great specificity of the phenomenon, which is of course a reflection of the specificity well known in other fields of the chemistry of surface forces. The high specificity of the method extends even to stereochemical isomers, for example *cis-trans* azo compounds. Tswett's method is used as a standard procedure for separating many other classes of substances, such as steroids, lipoids, terpenes, various derivations of benzene, naphthalene, and

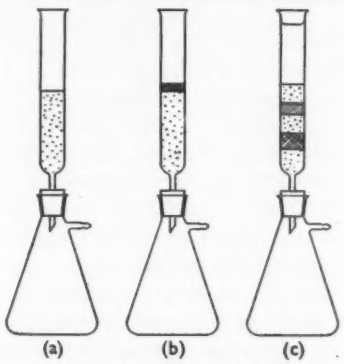


FIGURE 1 – *Tswett's original experiment.*

indene, heterocyclic compounds, alkaloids, vitamins, antibiotics, porphyrins, and bile pigments. Some recent reviews summarize the progress made, and in them detailed references are to be found [2, 3].

There are certain practical requirements which must be fulfilled in carrying out adsorption chromatography according to the method of Tswett. The adsorbent should have, in the solvent being used, the greatest possible adsorption specificity for the substances it is desired to separate. It is essential that adsorption and desorption take place rapidly and with complete reversibility, as otherwise the zones will become too extended and may overlap, causing losses on the column. The adsorbent should be easy to pack into a uniform column; uniformity is essential if the solution is to pass through without too much distortion of the zones. Some of the most commonly used adsorbents are alumina, silica gel, calcium carbonate, magnesium oxide, charcoal, sugar, and talc. A rational theory of the behaviour of substances on columns would require a detailed knowledge of the relevant adsorption isotherms in a number of pure and mixed solvents. Very few such data are available, probably because of the difficulty of preparing adsorbents which are sufficiently reproducible. Thus, although in present-day chemistry chromatography plays a role at least as important as distillation, the theory of the former method is not nearly so well known as that of the latter. Chromatographic behaviour depends upon a great many factors—a circumstance to which the method owes its great versatility—and not, as does distillation, upon a few well-known physical quantities. Some of the recent modifications of chromatography, especially partition and ion-exchange methods (see below), are based upon phenomena which are, as we shall see, more readily amenable to theoretical discussion; these are easier to put on a rational basis than is adsorption chromatography, where we still depend mostly upon empirical rules.

With a polar adsorbent (alumina) in a non-polar solvent (benzene, petroleum), development of the chromatogram occurs on mixing the solvent with increasing amounts of a polar solvent (methanol, ether). With a non-polar adsorbent the reverse is true (e.g. charcoal in aqueous media). Elutropic series have been worked out for such systems, with the added solvents ranged according to their eluting power on a given column material (see, for example, Trappe [4]). Chromatographic sequences for various substances have been established with certain adsorbent-solvent pairs.

From work of this kind some general conclusions can be drawn as to the structural characters which are of decisive importance in determining the adsorption affinity. Polar groups, like —OH and —COOH, will increase the adsorption on a polar adsorbent in a non-polar medium. Under the same conditions, double bonds also will tend to increase adsorption. On charcoal, in aqueous media, adsorption in homologous series increases regularly with increasing molecular weight, following Traube's rule for the influence of an added $-CH_2$ group on the surface tension [5].

TABLE 1

Adsorption sequence of some xanthophylls: (I) when developed on magnesia with light petroleum + 25 per cent. acetone, and (II) on sugar with light petroleum + 0·5–1·0 per cent. propyl alcohol. (After Strain, Manning, and Hardin.)

I	II
Neoneoxanthin A	Neoxanthin
Neoneoxanthin B	Peridinin
Neoxanthin + zeaxanthin	Neofucoxanthin A
Fucoxanthin	Neofucoxanthin B
Peridinin	Violeoxanthin
Violeoxanthin + lutein	Violaxanthin
Dinoxanthin	Fucoxanthin
Tareoxanthin + violaxanthin	Tareoxanthin
Taraxanthin	Taraxanthin
Cryptoxanthin	Zeaxanthin + lutein
	Cryptoxanthin

Some progress has also been made in the preparation of standardized adsorbents for chromatography, and in testing them with standard dye mixtures. An interesting result emerging from this kind of work is the striking influence of the moisture content of alumina (and probably of many other adsorbents) on its power of adsorption from organic solvents. This seems to be related to the effects which form the basis of partition chromatography.

CHROMATOGRAPHIC APPARATUS

In working with colourless substances, there has been a general tendency during recent years to follow the course of the chromatographic separation by observations on the percolate leaving the column, rather than on the column itself. The distribution of the various components in the chromatogram can be determined much more accurately and conveniently by this method, which is, indeed, essential in experiments concerning the formal theory of chromatography. Such an arrangement lends itself easily to automatic devices, such as that shown in figure 4, where a microinterferometer is coupled to the end of the column [6]. By reading the refractive index of the effluent at short intervals, as it leaves the column, one obtains an almost continuous record of the concentration distribution with volume. Other physical properties, such as conductivity, light absorption, and potentiometric functions can be utilized. Curves obtained in experiments of this type are shown in figures 7–9. Another device, which has found particularly extensive use, is the automatic fraction collector due to Moore and Stein [7]. Here, small fractions of the effluent are collected in a large number of test-tubes fixed in a horizontal wheel, which rotates sufficiently to move a new test-tube under the outlet of the column as soon as a predetermined number of drops have been collected. Other forms operate on a time or weight basis. At the conclusion of the experiment the contents of each test-tube are analysed for the substances under investigation. In many cases, a combination of the fraction collector with continuous concentration registration, similar to that obtained by the microinterferometer (figure 4), would approach the ideal, as the location of the various components in the liquid chromatogram would then allow a considerable reduction in the number of fractions to be analysed.

In chromatographic work carried out in the author's own laboratory, it has been found of advantage to use a column made in sections, as shown in figures 2 and 4. Such columns are easy to pack evenly. The material used is stainless steel, or, if contact with metal must be avoided, polythene or glass in collars of stainless steel. It is often useful to make the lower sections of a smaller diameter; such an arrangement has been shown by Claesson and Hagdahl to act as a 'front sharpener'.

For work on a micro-scale, filter-paper chromatography is usually the method of choice. One can, however, also use very narrow columns, and collect the percolate drop by drop on filter-paper allowed to pass slowly under the outlet of the column. An apparatus for this purpose has been constructed by Drake in the author's laboratory (figure 5), and has been found useful for work with very small charcoal columns. The filter-paper is placed on a revolving cylindrical drum, the movement of which is geared to a screw which moves the column parallel to the axis of the drum in about ten hours. Each drop gives a spot on the paper, and the spots form a spiral. The paper can be sprayed with suitable reagents for localization of the substances which have been separated.

Drake [8] has combined this arrangement with an automatic fraction collector; only a small fraction of the percolate thus goes to the filter paper.

FORMAL THEORY

The behaviour of a substance which travels through a chromatographic column in a given medium depends upon the affinity of the substance for the column-material in the medium. Usually we do not know this affinity, and, particularly, we do not know how it depends upon the concentration of the substance, which affects the adsorption isotherm, or upon the composition of the medium. If we assume that the weight adsorbed per gram of column material is m and that the concentration in the liquid medium is c, we may put $m = f(c)$, where f may be any function. Usually the isotherm described by this equation is somewhat curved towards the c-axis (Langmuir isotherm, Freundlich isotherm), although there may be an approximately linear relationship between m and c (partition isotherm).

If a solution of the substance of concentration c is allowed to percolate through a column containing 1 g of the adsorbent, we see that the column will first be saturated with this substance when a volume $f(c)/c$ has passed containing the weight of substance which can be adsorbed by 1 g of adsorbent. Thus, in the beginning only pure solvent will flow out, and not until the 'retention' or 'break-through' volume $f(c)/c$ has been reached

will the substance appear, usually as a sharp front. In studying chromatographic separations by observations on the percolate, as described in the preceding section, one usually plots the concentration as a function of the volume which has passed through, taking a volume corresponding to zero adsorption as the origin (see, for example, figures 7–9). In such a diagram, the volume co-ordinate for a front or a zone of constant concentration G is $a \,.\, f(c)/c$, where a is the weight of the column-material. It is to be noted that this expression is perfectly general, and holds whatever the physical basis of the affinity between the substance and the column-material (adsorption, partition, or other possible forces). One must assume, however, that equilibrium is reached at a rate which is very high compared with the rate of flow. When the separation is followed by direct observation on the column, or in paper chromatography, it is more convenient to define the position of a zone or a front as the ratio between the distances of travel for the zone and the pure solvent, the so-called R_F values, introduced by Martin and Synge [9]. The R_F value is of great practical convenience; it may be simply related to the 'break-through' volume in the following way. Suppose 1 g of column material occupies a volume of 1 cc, and that it contains Δv cc of the solution. When the adsorption front reaches the bottom of the column it has thus travelled a column volume of 1 cc, and a solution volume of Δv cc. The solvent front has travelled a solution volume of $\Delta v + \frac{f(c)}{c}$ cc, which corresponds to a column of $1 + \frac{1}{\Delta v} \,.\, \frac{f(c)}{c}$ cc. Thus

$$R_F = \frac{1}{1 + \frac{1}{\Delta v} \,.\, \frac{f(c)}{c}} = \frac{\Delta v}{\Delta v + \frac{f(c)}{c}}.$$

For the discussion in this section we will use the first mode of expression, and thus assume that the chromatogram is represented by a curve obtained by plotting concentration determinations in successive fractions of the percolate as a function of percolate volume. It has been suggested [10] that we may distinguish three main types of chromatograms, as shown in figure 3. The first type (upper figure) is obtained by allowing a solution containing one or more components to pass through the column, and observing the position and concentration of each front in the percolate. This has been called frontal analysis; it obviously represents only a partial separation, since the zones overlap. Nevertheless, the method is sometimes quite useful—for example, in studying the homogeneity of substances. It has been used particularly by Claesson [5] for analysis of mixtures of fatty acids and other substances. From the concentration in each step can be calculated the composition of the original mixture.

The second type of chromatogram, obtained by elution analysis (figure 3, middle), is essentially the same as that obtained by Tswett. A small amount of the mixture is adsorbed at the top of the column, and subsequently washed down the column by application of a suitable eluting solvent or solvent mixture. The resolving power of the elution depends chiefly on the character of the $f(c)$ function discussed above. In the simplest and most favourable case, $f(c)$ is a straight line, that is, the weight bound to the column material is proportional to the concentration. This is the case in dilute solutions of substances obeying the Langmuir isotherm, and also in ideal partition, where Henry's law holds. In this case, $f(c)/c$ is independent of concentration, and thus all concentrations of a given substance travel at the same rate. The zones will therefore move undistorted through the column, if it is ideally packed, and the position of each zone in the percolate will be independent of its concentration. Usually, however, the adsorption isotherm $f(c)$ is more or less curved, so that $c/f(c)$ decreases with decreasing c. This will cause the lower concentrations (at the rear end of a zone) to move more slowly, and thus the zone will gradually become extended and may get a very diffuse tail. This phenomenon of tailing, well known to all who have worked on chromatography, may easily become so pronounced that it seriously interferes with the separation. Obviously, if $c/f(c)$ for a fast component at certain concentrations falls below the value of this function for a following component, a complete separation is impossible. It is no exaggeration to say that one of the most important practical problems of chromatography is to eliminate tailing as far as possible.

Before discussing this in detail, however, we shall say something about the third main type of chromatography, viz. displacement analysis; when it can be realized, this is a way of avoiding tailing and presents some other interesting characteristics (figure 3, lower). Here, again, a small sample is introduced at the top of the column, but instead of applying an eluting agent we add a solution of a substance—the displacing agent—which is adsorbed more strongly than any of the components to be separated. Owing to mutual competition for

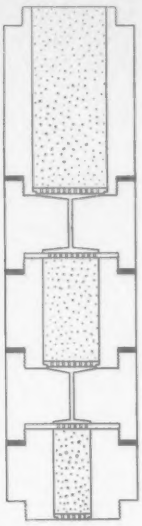


FIGURE 2 – *Chromatographic column built in sections.*

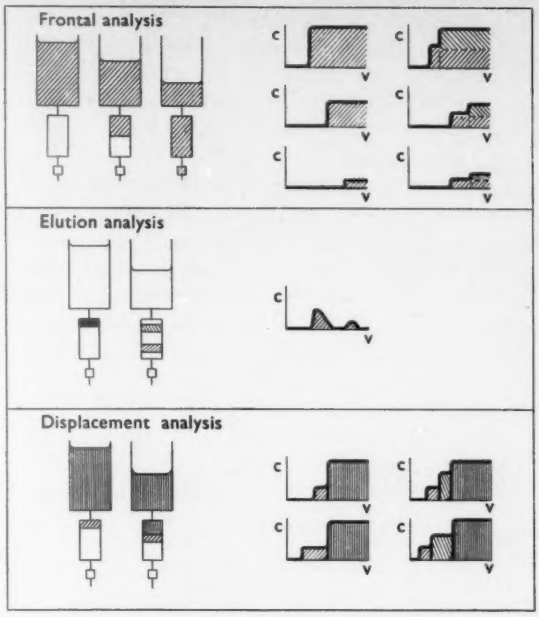


FIGURE 3 – *Three types of chromatogram.*

the adsorbent, which is so common in surface phenomena, the components arrange themselves in a succession of adjoining zones, each of a constant, characteristic concentration. The explanation of this phenomenon is seen in figure 6, which shows adsorption isotherms for a number of substances, with the displacing agent D at the top. We may draw a speed line OD through the origin which represents constant $c/f(c)$ values, and thus is the locus for concentrations which travel at the same rate through the column. The intersections of this line with the isotherms give us the zone concentrations in the chromatogram, as shown at the bottom of figure 6. It should be noted that in this case all zones move at the same rate as soon as a stationary state has been reached. Tailing is largely eliminated, because any trace of, say, substance A which tended to lag behind into the zone of B will find itself surrounded by a substance which is more strongly adsorbed than itself; this means that A will have to travel back to its own zone.

A detailed theory of this and the other chromatographic separation processes has been worked out by several authors. Particular reference should be made to the Faraday Society discussion on chromatographic analysis [3].

SYSTEMATIC QUANTITATIVE CHROMATOGRAPHIC STUDIES ON CHARCOAL COLUMNS

Examples of actual separation experiments by these procedures, obtained with charcoal columns and by micro-interferometric observations on the percolate, are shown in figures 7–9. Table 2 gives the specific retention volumes for a number of amino-acids and peptides on charcoal. It is seen that adsorption generally increases with increasing molecular weight, and that the aromatic amino-acids have particularly strong adsorptions.

Charcoal usually gives strongly curved adsorption isotherms and, without special precautions which will be discussed below, does not lend itself

TABLE 2

Retention volumes in the adsorption of some amino-acids and peptides on active carbon (Carbo Activ Schering)

Substance	*Ret. vol. (ml./g carbon)*	*Substance*	*Ret. vol. (ml./g carbon)*
Alanine	0·3	Phenylalanine	62·5
Hydroxyproline	2·0	Glycyl-glycine	3·5
Proline	2·5	Leucyl-glycine	18·2
Valine	3·2	Leucyl-glycyl-glycine ..	29·8
Leucine	7·7	Glycyl-alanine	4·0
*Iso*leucine ..	9·2	Valyl-alanine	22·0
Methionine ..	12·4	Alanyl-leucyl-glycine ..	34·4
Histidine ..	15·0	Glycyl-leucyl-alanine ..	42·5
Arginine ..	40·4	Glycyl-leucyl-glycine ..	38·0
Tryptophane ..	76·5		

so well to elution experiments. The best results are obtained by displacement analysis, using very strongly adsorbed displacers, like cetylpyridinium bromide. The amount of material which may be handled by the method is considerable, as zone concentrations may be comparatively high, and it is therefore particularly suitable for preparative work (see also the work by Partridge [25] with amino-acids on ion-exchange columns, quoted below). The method has been used with advantage in the separation of gases on charcoal [5, 10]. It is a disadvantage—in comparison with elution methods—that the zones are not separated by empty regions but are in close contact; thus a certain mixing at the boundaries cannot be avoided. Also there is often some tailing of one zone into another, probably because of slow attainment of equilibrium. In the author's laboratory we have tried to avoid this difficulty, and thus to make the method more applicable to analytical problems, by introducing what we have called carrier displacement [12], which essentially amounts to interposing other substances between the zones. The principle is illustrated in figure 10. A displacement analysis is set up in the normal way—for example, with a series of homologous alcohols and their isomers. If the system contains also a mixture of say amino-acids, these will arrange themselves in the succession, and each amino-acid will place itself between two zones of alcohols, one with a somewhat smaller and the other with a somewhat higher adsorption affinity. Thus it is found that in such a system the amino-acids are localized in the following way (table 3 and figure 11):

TABLE 3

Carrier frontal analysis of amino acids on charcoal in 0·1 N HCl

Methanol/water	Glycine, alanine
Ethanol/water	Aspartic acid
Ethanol/methanol	Proline, oxyproline
Sec. propanol/ethanol	Glutamic acid
Propanol/ethanol	Valine, leucine
Butanol/propanol	Methionine
Iso-amyl alcohol/butanol	Phenylalanine
Iso-amyl alcohol/*tert.* amyl alcohol	Tyrosine, phenylalanine

In this method the amino-acids become completely separated by the interposed zones of alcohols, and can be located with the aid of the carrier system. Such small amounts of amino-acids can be used as would otherwise escape the interferometric observation method employed. After isolation of the zones the alcohols are evaporated,

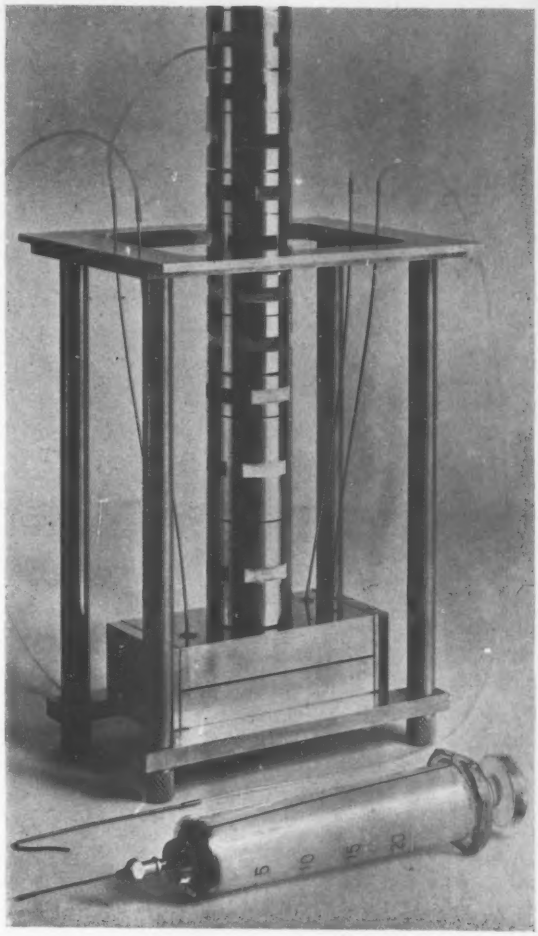


FIGURE 4 – *Microinterferometer attached to column for observation of chromatographic separation in the effluent.*

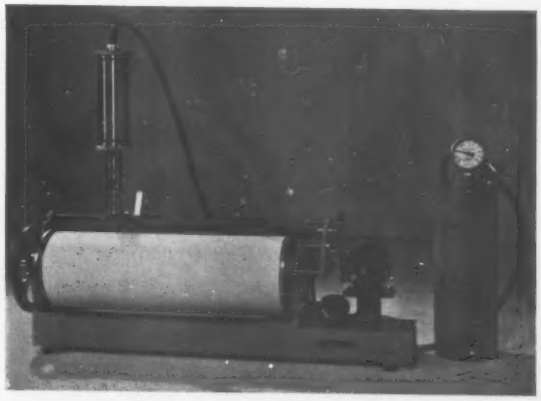
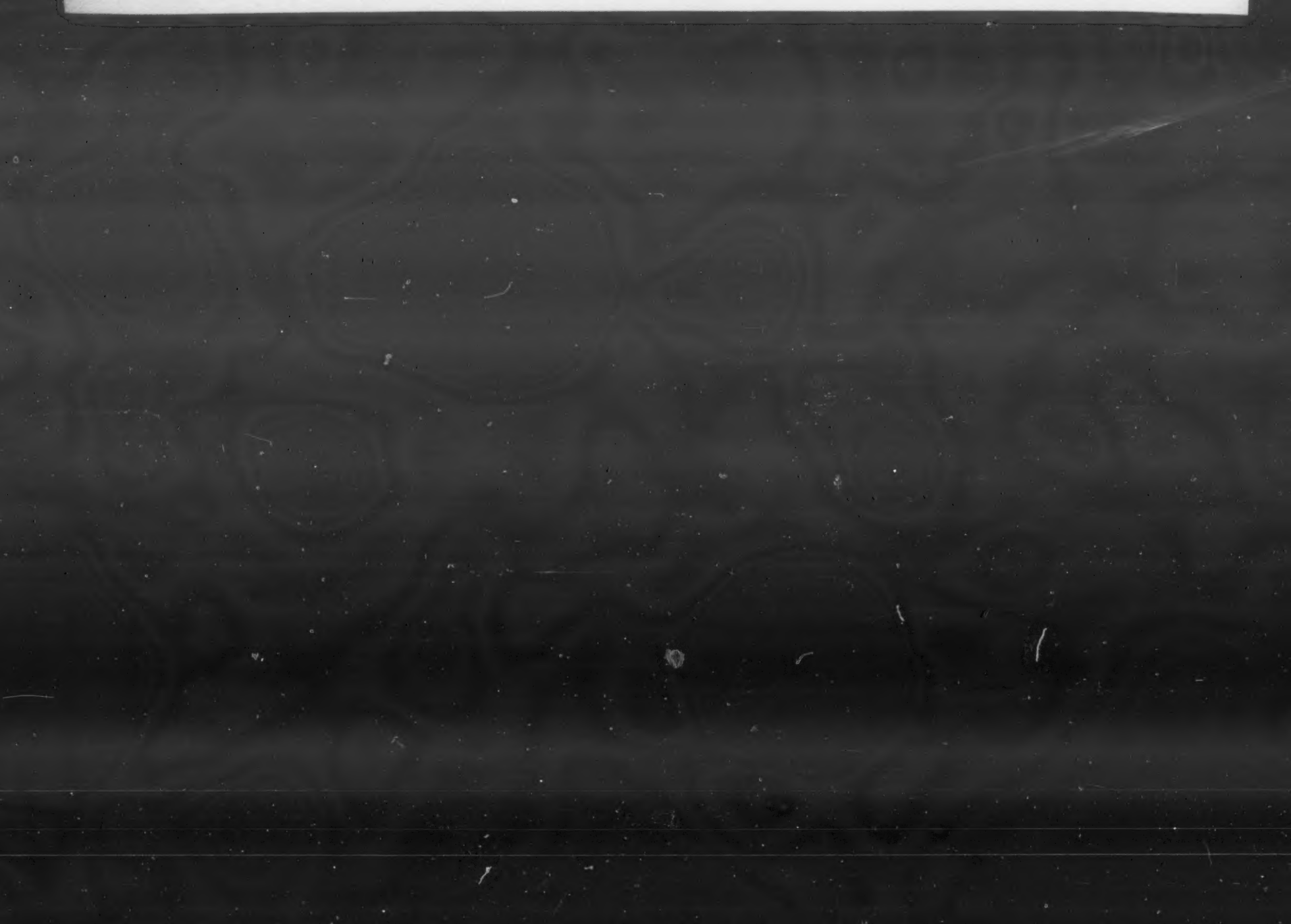


FIGURE 5 – *Drum apparatus for collecting effluent drops from microcolumns.*



and the individual amino-acids thus isolated. This method has been used in the purification of peptides, for example ACTH protein hydrolysates and bacitracin. It would seem that the carrier principle might also find useful application in other forms of chromatography.

There are, however, some limitations to this method. The components of the carrier system must, naturally, belong to a class of substances different from those of the system we want to separate, in order that they may be easily removed at the end of the experiment. We have found in our studies of adsorption isotherms in chromatographic systems that isotherms for amino-acids may be of quite another type from isotherms for homologous alcohols. In order that displacement shall occur in a system containing the substances A and B, it is not sufficient that B should be more strongly adsorbed than A when each is studied separately. It is also necessary that B in A should be more strongly adsorbed than A, and that A in B should be less strongly adsorbed than B. This appears to be the case with members of one and the same homologous series, and should always hold when the Langmuir adsorption isotherm is valid. In mixtures of substances of quite different character there may be exceptions to this rule, and displacement will then fail [13].

These studies of the adsorption of amino-acids, sugars, and other substances in the presence of eluting and displacing agents, such as various alcohols, have also thrown some light on the

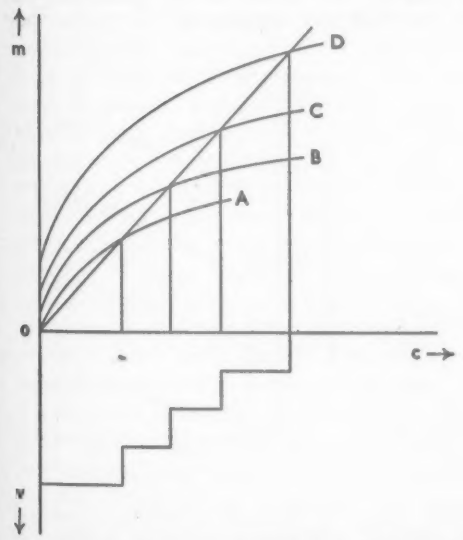


FIGURE 6 – *Diagram showing the principle of displacement development.*

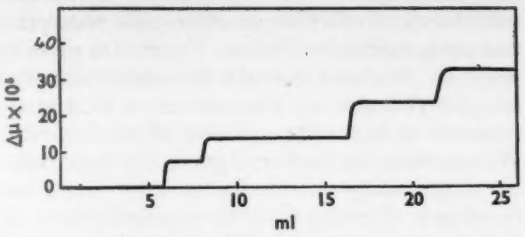


FIGURE 7 – *Frontal analysis (interferometric method) of a mixture of four fatty acids, with* 8, 10, 14, *and* 16 *carbon atoms, in ethyl alcohol on a charcoal column. (After Claesson.)*

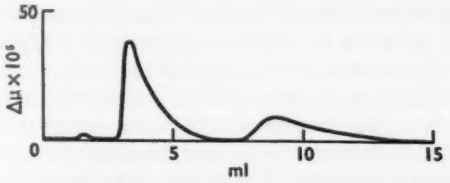


FIGURE 8 – *Elution analysis (interferometric method) of a mixture of lauric and palmitic acids in ethyl alcohol. The small peak to the left is due to water. (After Claesson.)*

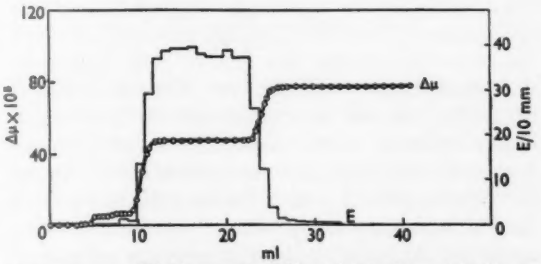


FIGURE 9 – *Displacement, followed interferometrically, of tryptophane by zephiran chloride. The tryptophane zone has been observed also by its ultraviolet extinction at* 270 mμ *(curve E). (After Hagdahl and Tiselius.)*

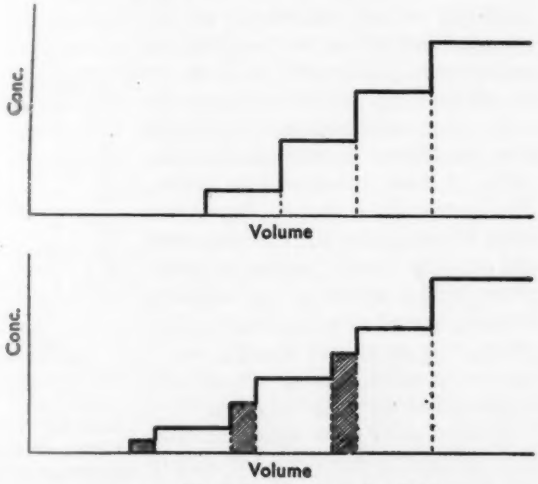


FIGURE 10 – *The principle of carrier displacement.*

mechanism of other chromatographic adsorption processes, especially elution. Figure 12*a* gives an example. It shows how the adsorption isotherms for phenylalanine on charcoal are shifted in the presence of increasing amounts of ethyl alcohol. We see that the isotherm gradually approaches the linear shape which is the most favourable for elution if tailing is to be avoided (see p. 8). Other substances, especially those strongly adsorbed compounds which are used as displacers, show another effect (figure 12*b*). They appear to act as saturators, that is, they block some of the available surface of the adsorbent, presumably the most active spots, without appreciably straightening the isotherm. It is often of advantage to treat the adsorbent with saturators before starting the chromatographic experiment, as losses due to irreversible adsorption may thus be eliminated.

It appears that the action of saturators and eluting agents may be described as an effect on the constants a and b respectively in the Langmuir adsorption isotherm:

$$m = \frac{abc}{1 + bc}.$$

A reduction in a will decrease the maximal adsorption, but will not make the isotherm more linear, whereas a reduction in b will not reduce maximal adsorption, but will definitely make the isotherm approach a straight line. If, as has been emphasized repeatedly above, an ideal eluting agent should make the isotherms of the substances as closely linear as possible, we should thus have an idea of how this is accomplished in terms of an adsorption isotherm. Some eluting agents act simply by increasing the solubility of the substances on the column, but this is not as common as is generally believed. Alcohols act as efficient eluents for amino-acids and sugars on charcoal, although they are known to decrease the solubility of these substances in water. This action is therefore dependent upon effects similar to those discussed above. The eluting action of phosphate buffer solutions on alumina columns is probably both a solubility effect, due to a shift in *p*H, and a displacing effect, due to the affinity of phosphate for such columns.

If the mixture to be separated contains several components of widely different adsorption affinities, it is not be be expected that they can be eluted with an eluting agent of one concentration only. As is well known, it is a common practice in the elution chromatography of such systems to apply portions of the eluting agent in successively increasing concentrations. In the Uppsala laboratory, Alm and Williams [14] have attempted to apply a continuously increasing concentration of the eluent, thus developing the chromatogram by gradient elution (figure 13). In this way, each component will gradually find itself surrounded by an eluent of the critical concentration, which will make it move in an almost ideal fashion. Tailing will be greatly suppressed, as the rear of a zone is always in a stronger eluting medium than the front. The column is fed with eluent from a mixing chamber in which a given volume of water receives a constant supply of, for example, ethyl alcohol. An example of gradient elution of a mixture of saccharides, produced by hydrolysis of α-Schardinger dextrin, is shown in figure 14. The yield of the different components is 95–100 per

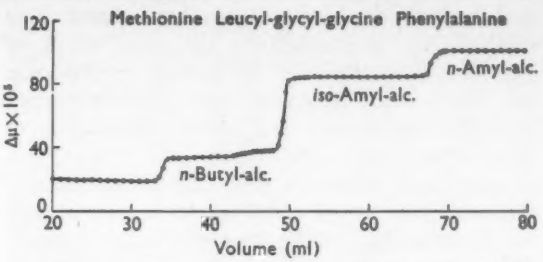


FIGURE 11 – *Separation of amino-acids by carrier displacement. Eluent analysed interferometrically.*

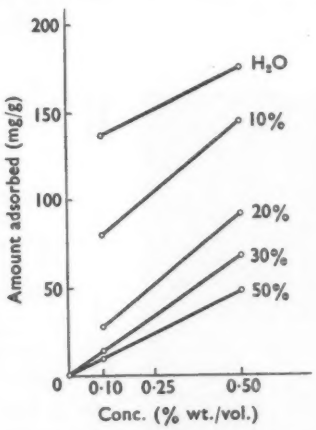


FIGURE 12*a* – *Adsorption isotherms of phenylalanine on charcoal in presence of different concentrations of ethyl alcohol.*

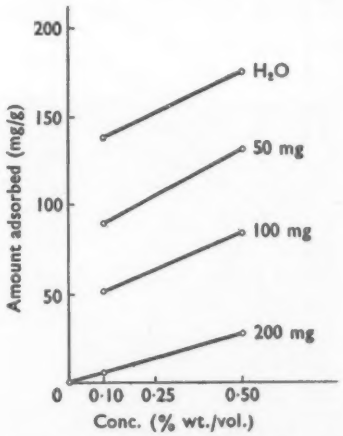


FIGURE 12*b* – *Adsorption isotherms of phenylalanine on charcoal in presence of different concentrations of a saturator (cetyl alcohol).*

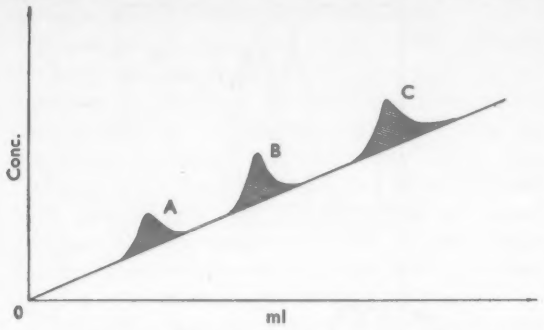


FIGURE 13 – *Gradient elution. (Schematic diagram.)*

cent. This method appears to have great advantages in the study of complicated systems. With pre-treated charcoal it seems possible to investigate also substances of fairly high molecular weight; the α-Schardinger dextrin had a molecular weight of about 1000.

PARTITION AND PAPER CHROMATOGRAPHY

There is no doubt that the most important developments in chromatography during recent years are the introduction of partition chromatography, with its various modifications on filter-paper media, and ion-exchange chromatography. It is interesting to note that these new methods were originally developed in connection with separation problems in two fields of the highest current importance, namely amino-acids and peptides on the one hand, and rare earths and fission products from the nuclear fission piles on the other.

Partition and paper chromatography were described a few years ago in an article in *Endeavour* [15] by one of the inventors of these methods, A. J. P. Martin, and I shall therefore limit myself here to some general considerations. Martin and Synge were led to their discovery [9] by their attempts to develop a counter-current extraction method for amino-acids present in hydrolysates of wool. To obtain a sufficient resolution, a large number of extraction steps are required, and they conceived the brilliant idea of letting wet grains of starch or silica gel act as carriers for one liquid phase (water), while the other phase (organic solvent) was allowed to percolate through a layer or a column of these grains, thereby enormously increasing the number of theoretical plates. This arrangement could also be regarded as a chromatographic column of a new type, and so an interesting form of chromatography, as an extreme case of counter-current extraction with a very large number of theoretical plates, could be worked out quantitatively. The possibilities in selecting columns suitable for chromatographic separations have thus been enormously increased. A great many solvents have been found suitable, and successful separations have also been made by reversed phase partition chromatography, using an organic solvent as a stationary phase, supported by a suitable (hydrophobic) material, and water or other hydrophilic solvents as the mobile phase [27]. Moreover, the choice of the partition system can be based upon rational considerations, as the partition of various types of substances between a great many different solvent pairs is well known.

Equally important is the fact that in ideal partition the function $c/f(c)$, which determines the rate of movement on the column, is a constant (equal to the partition coefficient). As a consequence of this fact, the zones move without appreciable spreading, and their positions in the chromatogram are reproducible and well defined.

The method has rapidly come into general use. Its most striking achievement is perhaps in the amino-acid analysis of proteins, particularly in the work of Stein and Moore [16], and in separations of sugars, fatty acids, and other comparatively simple substances. Partition chromatography has also played an important role in the separation of dinitrophenyl derivatives from protein hydrolysates which Sanger has introduced [17].

The capillary analysis used by Schönbein and by Goppelsroeder about ninety years ago, following earlier experiments by F. F. Runge, may very well be regarded as a predecessor of chromatography. These authors separated dyes and other substances by allowing solutions to rise in strips of filter paper. The use of filter-paper as carrier of the immobile phase in partition chromatography, as introduced by Consden, Gordon, and Martin [18], provided an extremely simple ultra-micro method of separation, which is now a routine method in most biochemical laboratories. As a method of qualitative analysis, particularly of

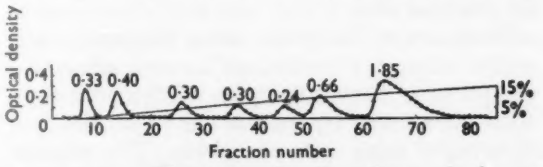


FIGURE 14 – *Chromatography of a mixture of mono- to hexa-saccharides obtained by gradient elution of an acid hydrolysate of α-Schardinger dextrin. Gradient: 0–20 per cent. ethanol. Adsorbent: Darco G60 charcoal, pre-treated with a 1 per cent. solution of stearic acid. The peak to the extreme right corresponds to unhydrolysed α-Schardinger dextrin. (After R. S. Alm, to be published.)*

hydrolysis products of proteins and carbohydrates, and of intermediates in metabolic processes in the living organism, it has already given much new information which would have been very difficult to obtain by other methods. The ingenious two-dimensional chromatogram, and the introduction of a spraying procedure for location of the spots, contribute to make the method both sensitive and specific. In some cases it has been possible to employ paper chromatography for quantitative analysis. Inorganic analysis on filter-paper has recently been reviewed in this journal [28].

Partition chromatography experiments are usually run as elution processes, and the fact that $f(c)/c$ is constant makes them very well suited for this practice. In some partition systems we may, however, have curved isotherms. This is the case, for example, if the aqueous phase contains a small amount of an acid, which significantly shifts the partition of a substance in the favour of this phase as a result of salt formation. In such systems, displacement methods should be useful. An interesting theory for such partition displacement processes has been worked out by Martin [19].

As Martin and Synge have shown, the R_F values in ideal partition chromatography can be calculated from known partition coefficients between bulk phases. The agreement found is sometimes satisfactory, sometimes not. There are many possible explanations for the deviations. It may very well be that the water taken up by the starch grains, the silica gel, or the filter-paper cellulose is not completely comparable with free water. Also, the specific adsorption forces of the solid material in the column may interfere. Even if the behaviour of substances in partition chromatograms is not always as simple as in the ideal case, the main advantages of the method, especially the well defined movement of the zones and the elimination of tailing, remain. The relation to known partition coefficients is usually good enough to allow prediction of the most favourable conditions for practical work.

It seems very likely that there are many cases which belong to a borderland between adsorption and partition chromatography. With some amino-acids, satisfactory separations can be obtained on filter-paper using only one phase. The requirements for ideal eluting agents in adsorption chromatography, as discussed above, and particularly the effects of alcohols on the adsorption of amino-acids on charcoal, seem to approach in a certain sense the conditions of partition chromatography; the effect of the alcohols should be to modify the adsorption affinity without interfering too much with the space available, so that the isotherm approaches a straight line. One must also remember that most separations in partition chromatography are run at very low concentrations, so that an adsorption isotherm would be very likely to approach the linear form.

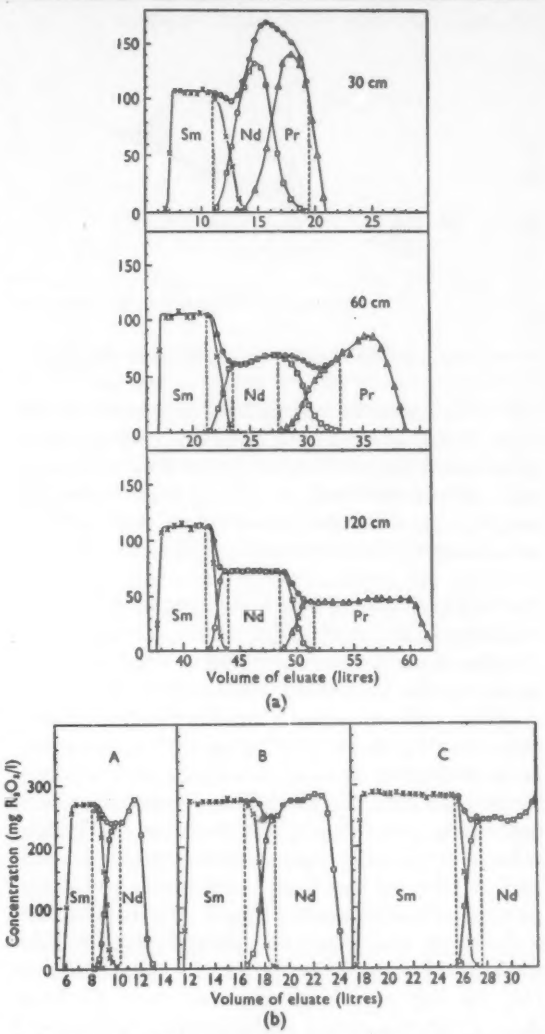


FIGURE 15 – *Chromatographic separation of rare earths (Sm, Nd, and Pr) on columns of Amberlite IR-100, using citrate solution at pH 5·30. Key:* ○, *total* R_2O_3; ×, Sm_2O_3; □, Nd_2O_3; △, Pr_6O_{11}. *Broken vertical lines indicate overlap of bands.* (a) *Elution from columns of 2·2 cm diameter and 30, 60, and 120 cm length respectively.* (b) *Illustration of effect of increasing column load and column length proportionately, using equimolecular mixtures of* Sm_2O_3 *and* Nd_2O_3. (A) 1·65 *g on column 2·2 × 30 cm;* (B) 3·30 *g on column 2·2 × 60 cm;* (C) 49·5 *g on column 2·2 × 90 cm. (After Spedding* [23].)

ION-EXCHANGE CHROMATOGRAPHY

Ion-exchange substances, originally used chiefly in water-softening procedures, have gained considerably in technical and scientific importance since Adams and Holmes, in 1935, succeeded in preparing synthetic resins of very high ion-exchange capacity, by condensing formaldehyde with polyphenols containing acidic or basic groups. The exchange properties of such resins can be varied within certain limits by introducing various acidic or basic groups into the nuclei.

During the war, as a part of the Manhattan project, this field was the subject of intense study, as it was found that the new resins could be used with advantage as column materials in chromatographic separations of rare earths and of radioactive fission products from the uranium piles. A number of new resins were developed (Amberlites, Dowex), some of them prepared in the form of small spherical particles, particularly well suited for packing into columns. A systematic study revealed that astonishingly good separations can be obtained on cation-exchange resin columns by fractional elution with solutions containing complex-forming organic acids, such as citric and oxalic acids, at controlled *p*H [20]. In buffered citric acid solutions the sequence of elution in the rare earth series from Amberlite IR–1 is the reverse of the atomic number [21]. Detailed reports of these experiments have been published by Tompkins, Spedding, and their collaborators [22, 23], and others. As an example of the success of these methods, even when applied on a large scale, it can be mentioned that Spedding reported in 1949 the isolation of about 300 g of pure ytterbium, 15 g of spectroscopically pure lutecium, and an almost equal weight of very rich thulium. Bars of pure lanthanum, cerium, praseodymium, neodymium, and yttrium, prepared from material isolated in this manner, were demonstrated by Spedding at the Faraday Society discussion on chromatographic analysis, held at Reading, England, in 1949. Radioactive isotopes can be identified in the effluent from the columns by their radiation; thus radio-isotopes of neodymium and of element 61 have been isolated.

It appears that this type of chromatography is essentially a fractional elution based upon increased solubility. Some chromatographic diagrams, like that shown in figure 15, are, however, typical displacement diagrams, and for large-scale separations the greater capacity of displacement methods should be favourable.

Columns of ion-exchange resins, as well as columns of other ion-exchange materials, such as the sulphonated carbon Zeocarb, are rapidly being introduced for the separation of organic substances in aqueous solutions. Again, the most striking advance has been made in the amino-acid field. Moore and Stein, who applied partition chromatography in connection with their automatic fraction collector, have recently shown, in very careful analyses of amino-acids in protein hydrolysates, that columns of cation-exchange resins can be used for this purpose, and may even offer some advantages over partition columns. The separations are performed on sulphonated polystyrene resin (Dowex 50) columns by eluting with hydrochloric acid of increasing concentration [24], or, more recently, by using buffer solutions of gradually increasing *p*H for the elution. Figure 16 shows an elution curve obtained by this procedure. The yield of most of the amino-acids is sufficiently good to make this method of great value for the analysis of complex amino-acid mixtures. Independently, Partridge and his co-workers [25] have successfully applied displacement analysis on ion-exchange columns for separations of amino-acids on a preparative scale.

It is very interesting to note that ion-exchange columns show a specificity which appears to depend not only on the electrochemical properties of the substances bound to the column. The sequence of amino-acids obtained by Moore and Stein (figure 16) bears a certain resemblance to the sequence obtained on charcoal (table 2). Thus a sufficiently selective action will probably be found also with many other substances, justifying

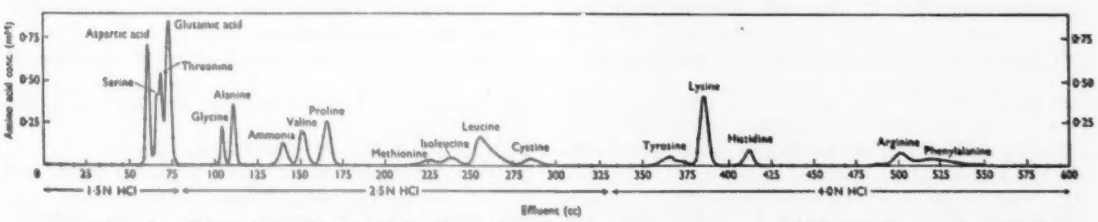


FIGURE 16 – *Chromatographic separation of amino-acids on an ion-exchange resin.* (*After Stein and Moore* [24].)

the hope that these materials may prove useful in various fields of chromatography. The resins appear to be superior in many ways to common adsorbents—above all, in their reproducibility—and their exchange properties have been studied in particularly great detail.

I should like to conclude this review by pointing out that the principles underlying chromatographic separation should be capable of generalization in different directions, which in some cases might lead to new methods of separation (see also [26]). Any process which will cause a zone of a substance to move along a column (or a similar arrangement), at a rate which has some relation to its specific physical or chemical properties, may be utilized for such a purpose. Such properties may be, for example, vapour pressure or solubility. Another possibility, which is now being explored by Synge and the author, is based upon the difference in frictional resistance which molecules of different sizes will meet when they are forced to move through a gel. This should give a separation according to molecular size. Zone electrophoresis in immobilized media, like glass powder, filter-paper, and various gels, somewhat resembles chromatographic procedures, and it should be possible to modify the methods of ultracentrifuging in the same direction.

REFERENCES

[1] KUHN, R., WINTERSTEIN, A., and LEDERER, E. *Hoppe-Seyl. Z.*, **197**, 141, 1931.

[2] ZECHMEISTER, L. and CHOLNOKY, L. 'Die Chromatographische Adsorptionsmethode' (2nd Ed.), Springer, Vienna, 1938. English translation by A. L. Bacharach and F. A. Robinson. Chapman and Hall, London. 1941.
ZECHMEISTER, L. 'Progress in Chromatography 1938–1947.' Chapman and Hall, London. 1950.
LEDERER, E. 'Progrès Récents de la Chromatographie,' Hermann et Cie, Paris. 1949.
CASSIDY, H. 'Adsorption and Chromatography.' Interscience Publishers, New York and London. 1951.
WILLIAMS, T. I. 'An Introduction to Chromatography,' Blackie and Son, London. 1946.

[3] *Chromatography* (Discussion), *Ann. N.Y. Acad. Sci.*, **49** (Act. 2), 141–326, 1948.
Partition Chromatography, Biochemical Society Symposia No. 3. Cambridge University Press, London. 1949.
Chromatographic Analysis, Gen. Disc. Faraday Soc., **7**, 1949.

[4] TRAPPE, W. *Biochem. Z.*, **305**, 150, 1940; **306**, 316, 1940; **307**, 97, 1941.

[5] CLAESSON, S. *Ark. Kemi Min. Geol.*, 23A, No. 1, 1946.

[6] TISELIUS, A. and CLAESSON, S. *Ibid.*, **15**, No. 18, 1942.

[7] MOORE, S. and STEIN, W. H. *Ann. N.Y. Acad. Sci.*, **49**, 265, 1948.

[8] DRAKE, B. *Nature*, **160**, 602, 1947.

[9] MARTIN, A. J. P. and SYNGE, R. L. M. *Biochem. J.*, **35**, 1358, 1941.

[10] TISELIUS, A. *Ark. Kemi Min. Geol.*, 14B, No. 22, 1940; **14B**, No. 32, 1940; **15B**, No. 6, 1941.

[11] PHILLIPS, C. S. G. *Gen. Disc. Faraday Soc.*, **7**, 241, 1949.

[12] TISELIUS, A. and HAGDAHL, L. *Acta chem. scand.*, **4**, 394, 1950.

[13] TISELIUS, A., HAGDAHL, L., and WILLIAMS, R. J. P. *Ark. Kemi Min. Geol.*, 1951 (in the press).

[14] ALM, R. and WILLIAMS, R. J. P. *Ibid.*, 1951 (in the press).

[15] MARTIN, A. J. P. *Endeavour*, **6**, 21, 1947.

[16] STEIN, W. H. and MOORE, S. *J. biol. Chem.*, **176**, 337, 1948; **178**, 53, 1949.

[17] SANGER, F. *Biochem. J.*, **45**, 563, 1949. *Biochem. Soc. Symposia No.* **3**, 21, 1949.

[18] CONSDEN, R., GORDON, A. H., and MARTIN, A. J. P. *Biochem. J.*, **38**, 224, 1944; **41**, 590, 1947.

[19] MARTIN, A. J. P. *Biochem. Soc. Symposia No.* **3**, 1, 1949.

[20] BOYD, G. E., SCHUBERT, J., and ADAMSON, A. W. *J. Amer. Chem. Soc.*, **69**, 2818, 1947.
BOYD, G. E., ADAMSON, A. W., and MYERS, L. S. *Ibid.*, **69**, 2836, 1947.
KETELLE, B. H. and BOYD, G. E. *Ibid.*, **69**, 2800, 1947.
BOYD, G. E., MYERS, L. S., and ADAMSON, A. W. *Ibid.*, **69**, 2849, 1947.

[21] MARINSKY, J. A., GLENDENIN, L. E., and CORYELL, C. D. *Ibid.*, **69**, 2781, 1947.

[22] TOMPKINS, E. R., KHYM, J. X., and COHN, W. E. *Ibid.*, **69**, 2769, 1947.

[23] SPEDDING, F. H., BOIGT, A. F., GLADROW, E. M., and SLEIGHT, N. R. *Ibid.*, **69**, 2777, 1947.
SPEDDING, F. H., BOIGT, A. F., GLADROW, E. M., SLEIGHT, N. R., POWELL, J. E., WRIGHT, J. M., BUTLER, T. A., and FIGARD, P. *Ibid.*, **69**, 2786, 1947.
SPEDDING, F. H., FULMER, E. I., BUTLER, T. A., GLADROW, E. M., GOBUSH, M., PORTER, P. E., POWELL, J. E., and WRIGHT, J. M. *Ibid.*, **69**, 2812, 1947.
SPEDDING, F. H. *Gen. Disc. Faraday Soc.*, **7**, 214, 1949.

[24] STEIN, W. H. and MOORE, S. *Cold Spring Harbor Symposia on Quantitative Biology*, **14**, 179, 1950.

[25] PARTRIDGE, S. M. *Biochem. J.*, **44**, 521, 1949; **45**, 459, 1949.
PARTRIDGE, S. M., BRIMLEY, R. C., and PEPPER, K. W. *Ibid.*, **46**, 334, 1950.
PARTRIDGE, S. M. and BRIMLEY, R. C. *Ibid.*, **48**, 313, 1951.

[26] SYNGE, R. L. M. *Gen. Disc. Faraday Soc.*, **7**, 164, 1949.
MARTIN, A. J. P. *Ibid.*, **7**, 332, 1949.

[27] WINTERINGHAM, F. P. W., HARRISON, A., and BRIDGES, R. G. *Nature*, **166**, 999, 1950.

[28] POLLARD, F. H. and MCOMIE, J. F. W. *Endeavour*, **10**, 213, 1951.

British scientific work in Spitsbergen

P. F. HUTCHINS

Although Spitsbergen was an important whaling station in the seventeenth century and was used as a base for attempts to reach the North Pole in the nineteenth, its scientific exploration has been undertaken only comparatively recently. British expeditions, generously supported by the government of Norway, which has exercised sovereignty over the islands since 1925, have played a leading part in the geological, glaciological, and ecological investigations.

In 1596, while sailing in search of a north-east passage, the Dutchman Willem Barents discovered Spitsbergen. At first, this new land attracted little attention and was thought to be part of Greenland. Henry Hudson, who revisited the islands in 1607, reported to his employers, the Muscovy Company of London, that large numbers of whales, seals, and walruses frequented the bays and fjords. Following this discovery, for many years fleets of whaling ships from England, Holland, and other countries visited Spitsbergen during the summer months. Excessive exploitation soon reduced the value of the fishery. The large shore establishments, some of which had known a summer population of several hundreds, were closed, and almost the only visitors to Spitsbergen during the eighteenth century were Russian trappers. Scientific exploration became prominent during the second half of the nineteenth century, and expeditions have since visited the islands regularly. They have originated from most European countries, but Swedish—and more recently Norwegian—expeditions have been predominant.

Coal was first discovered in Spitsbergen by the early whalers, though it was not mined until the beginning of the twentieth century. Several countries took part in the original prospecting, but mining is now carried out by Norwegian and Russian companies only. A British company which prospected the area around Billefjorden before and immediately after the 1914–18 war has never worked the coal found there; its mining rights were, however, recently renewed.

Until 1925 no nation exercised sovereignty over Spitsbergen. England, Holland, and Denmark had advanced claims at various times soon after its discovery, but these were never followed up. By a treaty signed at Paris in 1920, Spitsbergen and Bjørnøya (Bear Island) were awarded to Norway (whose control became effective in 1925), and these islands now form the province of Svalbard. The mining claims of several nationalities were protected by the agreement, and laws have since been enacted controlling exploitation of the mineral resources. Britain is one of the countries with special treaty rights in Svalbard.

Although Spitsbergen is situated in high latitudes, the climate is relatively mild, and during the summer months the western coastline is free from pack ice. The interiors of several of the larger islands are covered with permanent ice, but the majority of the glaciers are retreating, and extensive areas of low-lying ground are now ice-free.

EARLY BRITISH EXPEDITIONS

After the decline of whaling in the seventeenth century, English visitors to Spitsbergen were few. In 1773, an English naval expedition under Captain the Hon. C. J. Phipps (afterwards Lord Mulgrave) sailed north in two vessels, with orders to navigate towards the Pole. The ships were repeatedly prevented from sailing far beyond Spitsbergen by the pack ice, but while they were confined to the northern coasts some of the bays were mapped. This expedition was a new venture in the Arctic, and was the first essentially geographical expedition there. 'Phipps had nothing else to do but to explore. That is the fact to which the English expedition of 1773 owes its importance in Arctic history' [1].

A similar expedition in 1818 was again prevented by pack ice from reaching the Pole. Phipps' chart was proved inaccurate, and the north-west coast of Spitsbergen was resurveyed.

Sir Edward Sabine landed from a naval vessel at Indre Norskøya in 1823, to make pendulum and magnetic observations. He conceived the idea of measuring an arc of meridian in Spitsbergen, but was unable to gain support for the project in England. The Swedes took up the work, and many of their expeditions during the nineteenth

century were preliminary explorations for this purpose. The arc was finally measured during the years 1898–1902, by a series of Russo-Swedish expeditions.

The other British expedition of importance in the early part of the century was led by W. E. Parry, in H.M.S. *Hecla*, in 1827. This was another attempt to reach the Pole, by sledging over the pack ice from the northern coasts of Spitsbergen. The rapid southerly drift of the pack forced Parry to turn back after reaching 82° 40′ N. During his absence from the ship, Sorgfjorden (Treurenberg Bay) and part of the coast of Hinlopenstretet were mapped.

EXPLORATION OF THE INTERIOR

By the latter half of the nineteenth century the western coastline of Spitsbergen was well known, and during the summer months tourist ships often visited Isfjorden. Few travellers, however, had ventured more than a few miles inland. In 1873, A. E. Nordenskiöld, the famous Swedish traveller, sledged across the ice cap of Nordaustlandet. The interior of Vestspitsbergen was still almost unknown when in 1896 Sir Martin Conway, the British alpinist and explorer, crossed the island from west to east, starting at Adventfjorden. Two geologists, E. J. Garwood and J. W. Gregory, who went with him, afterwards published valuable glaciological observations. In the following year Conway and Garwood returned to Spitsbergen, and for the first time penetrated the area north-east of Billefjorden.

Between Sir Martin Conway's visits and 1914 W. S. Bruce, the Scottish polar explorer, was a member of several expeditions, most of them under the auspices of H.S.H. the Prince of Monaco. Expeditions led by Bruce investigated Prins Karls Forland, which had previously been neglected. In spite of low clouds and difficult travel inland, the whole island was surveyed in three summers (1906, 1907, and 1909), and what was perhaps the first detailed map of any large area within the polar regions was produced.

MODERN EXPLORATION

The end of hostilities in 1918 began a new phase in the exploration of Spitsbergen. The first stage of discovery and primary exploration was complete. Except for some of the eastern islands, the coastline was well known, and the interiors of most of the islands had been visited. The next stage of exploration involved more detailed surveys. Biologists could no longer be wholly occupied in recording new species. Only the general distribution of the geological formations was known. Accordingly, expeditions concentrated on smaller areas and more specialized problems.

In 1921, Oxford sent the first university expedition to Spitsbergen. It was primarily an ornithological enterprise, and during the cruise of the expedition ship, *Ternigen*, a survey was made of the birds along the west coast. Sixty-one species were then known from Spitsbergen. The expedition observed thirty-five species, of which twenty-seven proved to be breeding. Among these the turnstone (*Arenaria i. interpres*), the dunlin (*Erolia a. alpina*), and the ringed plover (*Charadrius h. hiaticula*) had not previously been known to breed in Spitsbergen. Interesting details of the courtship and habits of the red-throated diver (*Colymbus stellatus*) were recorded, as well as the breeding habits of several other species. A party based on the Scottish Spitsbergen Syndicate's huts, at the head of Billefjorden, investigated the fauna and flora, and three men sledged north-eastwards on to the highland ice of the interior. They visited part of the area originally seen by Conway and Garwood in 1897, and surveyed geologically north of Svanbergfjellet.

The Oxford (Merton College) expedition of 1923 was organized on a smaller scale. A sledge party of four, led by N. E. Odell, landed from the *Ternigen* in Hinlopenstretet. They travelled south-west towards Chydeniusfjella, and, after explorations immediately north of the area examined in 1921, rejoined their ship in Billefjorden. Meanwhile the *Ternigen* had cruised round the west and north-west coasts of Nordaustlandet and the northern fjords of Vestspitsbergen. Ecological observations supplemented those made in 1921.

The Oxford University Arctic expedition of 1924 was one of the largest British expeditions to have visited Spitsbergen. Three sledge journeys were made across Nordaustlandet, the first recorded since Nordenskiöld's pioneer journey of 1873. The expedition was one of the first to use a seaplane in the Arctic. In spite of damage and delays owing to bad weather, about seventy miles of the Nordaustlandet coastline were photographed from the air.

These three expeditions from Oxford made a contribution to exploration which is unique in the history of British associations with Spitsbergen. They were organized by Mr (now Sir) George Binney, who led the 1923 and 1924 expeditions. There was also continuity of membership, several members of the last two having accompanied the earlier expedition. The collections of various

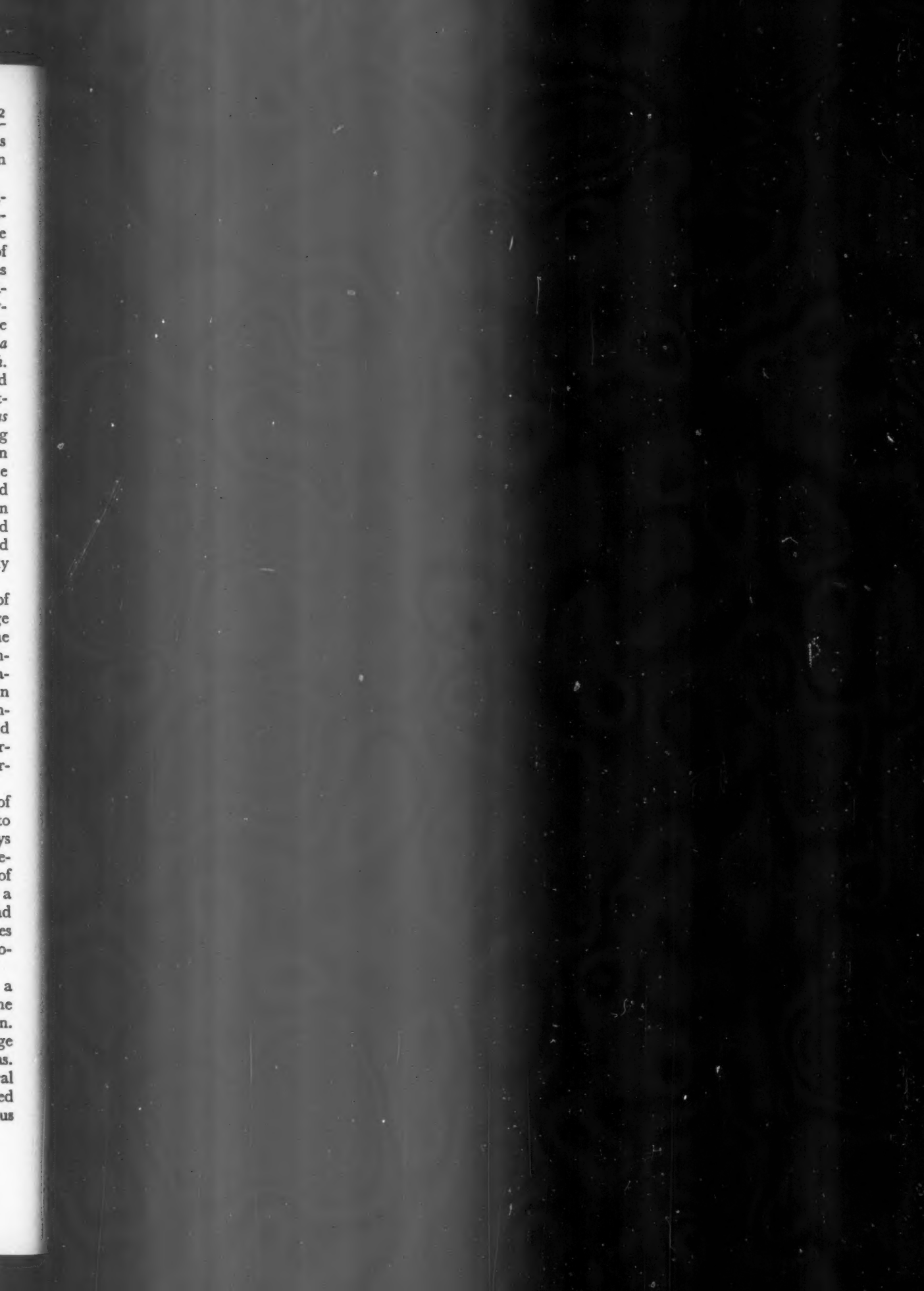


FIGURE 1 – *Gipsdalen, a long deglaciated valley east of Billefjorden.*

FIGURE 2 – *Ragnardalen, a valley near Billefjorden cut through almost horizontal Carboniferous strata. The scenery is typical of many partly deglaciated areas of central Vestspitsbergen.*

FIGURE 3 – *Surveying during a sledge journey. The mountains behind are capped by Upper Carboniferous limestones.*

FIGURE 4 – *The mountains of Finnlandveggen viewed from Chydeniusfjella.*

(*Photographs by courtesy of members of the Cambridge Spitsbergen Expedition, 1949.*)

animal and plant groups were submitted to specialists, who have described several new genera and species. The ecological observations have been discussed by V. S. Summerhayes and C. S. Elton [2]. They have shown that the general distribution of plant and animal communities in Spitsbergen is dependent upon climate, soil, manuring by sea-birds, and water supply. Four climatic zones were distinguished, characterized by different faunal and floral assemblages. These results, together with papers on ornithology, geology, glaciology, and other subjects, were published in various journals, and later collected together in two volumes as *Spitsbergen Papers* [3].

Since Binney's visit in 1924 two Oxford expeditions have visited Nordaustlandet. An expedition led by A. R. Glen wintered from 1935 to 1936. From the main base on the north-west coast they investigated the ionosphere, and the auroral displays were observed. Two stations were established on the western ice-cap, from which continuous meteorological and glaciological records were taken throughout the winter. At the central ice-cap station, the temperature and density of the snow, *firn* (rounded granules of ice about the size of small shot), and ice at various depths were recorded. These observations suggest that, although the surface details of supply and wastage of the western ice-cap of Nordaustlandet are similar in some respects to the Greenland type, it nevertheless resembles more closely the alpine type owing to its higher mean temperature [4]. It has been described as 'a characteristic sub-Arctic glacier cap' [5].

Aerial photographs of Nordaustlandet, taken in 1938 by the Norwegians, showed that since 1935 there had been a remarkable development on the southern coast. A glacier (Bråsvellbreen) appeared to have advanced over ten miles into the sea. Investigation of the causes and results of this phenomenon was delayed by the 1939–45 war. In 1949 a small Oxford expedition, led by J. M. Hartog, was able to visit the area and to examine the glacier during several sledge journeys.

The other area which has received most attention by British expeditions is the peninsula of Ny

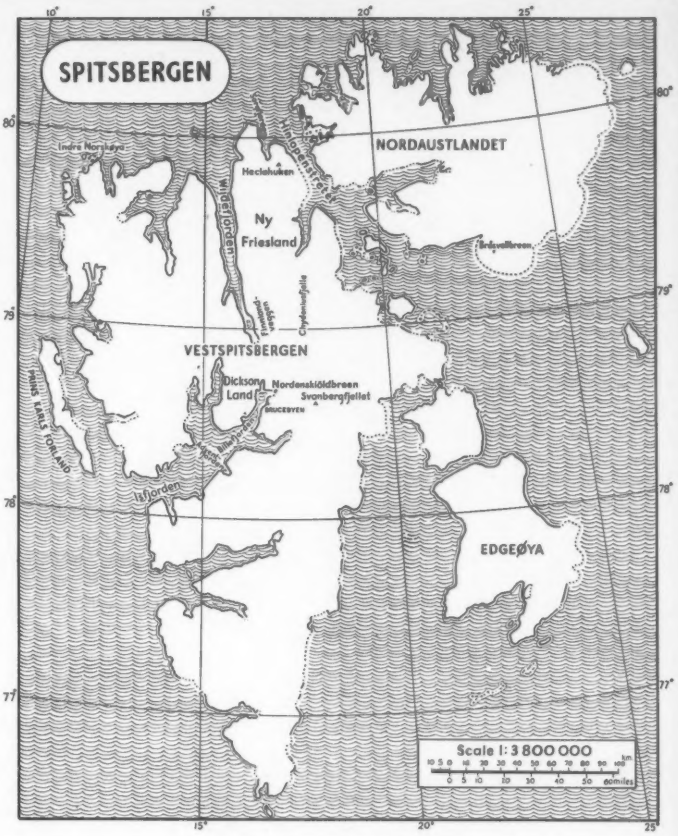
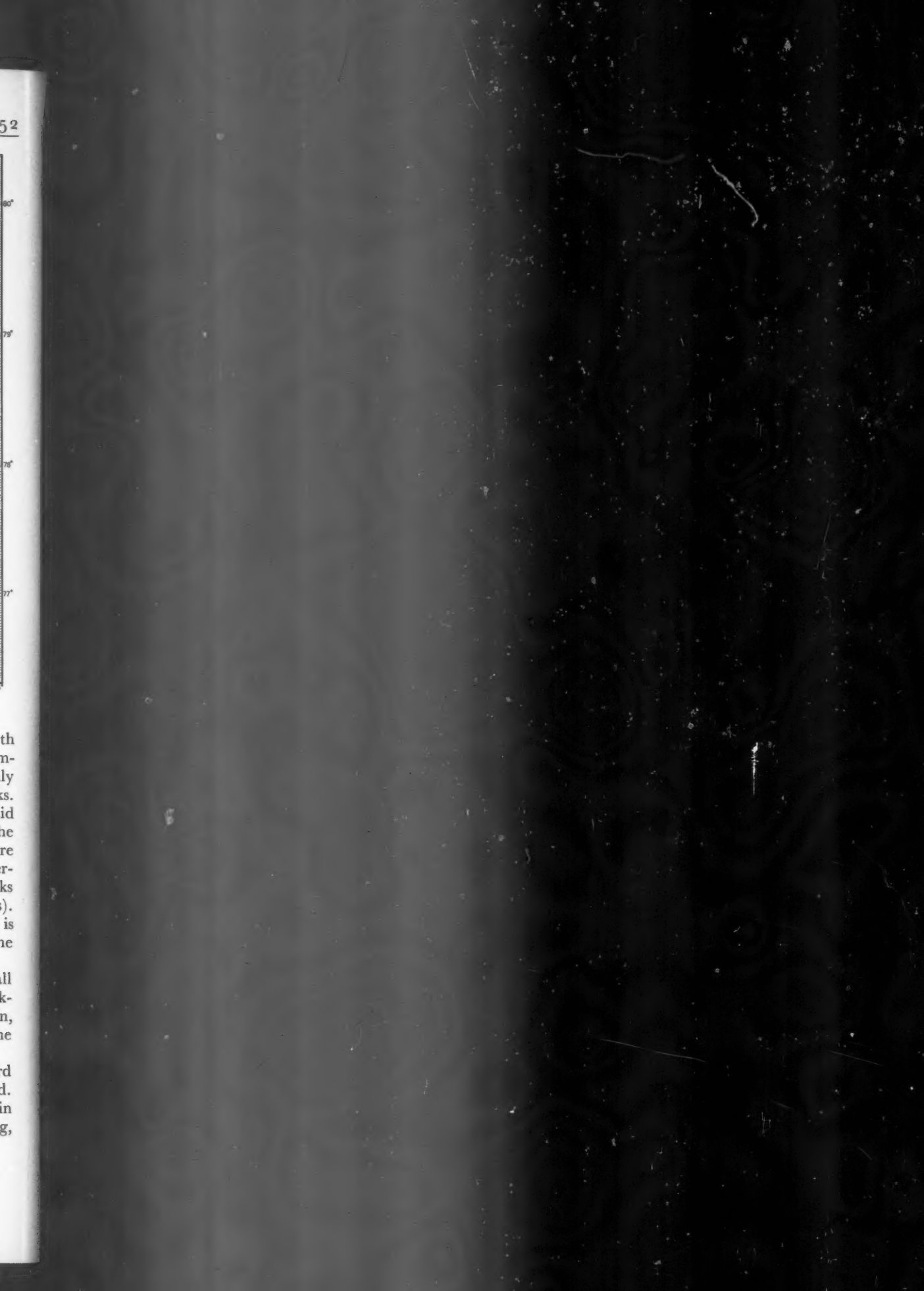


FIGURE 5 – *Map of Spitsbergen.*

Friesland and the region to the south on the north and east of Billefjorden. This area is largely composed of pre-Devonian rocks—some of them highly metamorphosed and intruded by igneous rocks. Around Billefjorden these older rocks are overlaid by coal-bearing strata of Carboniferous age. The mountains composed of these newer rocks are mostly ice-free, but the interior is covered by permanent ice through which the pre-Devonian rocks project as *nunatakker* (insular hills or mountains). In Finnlandveggen and Chydeniusfjella, the ice is restricted to valley glaciers flowing between the highest mountains in Spitsbergen.

During the summers of 1930 and 1932 two small expeditions from Cambridge, led by R. M. Jackson, surveyed the southern part of Finnlandveggen, and the petrology of the pre-Devonian rocks of the area was described.

Early in July 1933 three parties of an Oxford expedition were landed in northern Ny Friesland. These converged by different routes on the main base at the head of Billefjorden. W. L. S. Fleming,



who was in charge, led a geological sledge party down the length of Ny Friesland. A. R. Glen, leader of the whole expedition, remained with the base party in Billefjorden, whence a geological and survey party reconnoitred Dickson Land and a biological party worked in the vicinity of Nordenskiöldbreen.

A Cambridge expedition led by L. H. McCabe was at Brucebyen during the summer of 1938. The geomorphology and geology of Billefjorden and Finnlandveggen were studied. This geological work was followed up in 1949 by a larger Cambridge expedition, led by W. B. Harland.

The Carbo-Permian rocks of Billefjorden have been examined by a number of British geologists. The Scottish Spitsbergen Syndicate expeditions before 1923 proved the existence of large deposits of coal and gypsum, but the area was not completely mapped geologically. Further information collected by later expeditions, and a survey by the 1949 expedition, have enabled a revised stratigraphic correlation and geological map to be made.

The pre-Devonian rocks of Ny Friesland and Nordaustlandet are still imperfectly known. In Ny Friesland they consist of two contrasted series: a western series of highly metamorphosed marbles, schists, and gneisses, and an eastern (Hecla Hoek) series of limestones, slates, and quartzites. The exact relationship between the two series is uncertain. In central Ny Friesland, the 1923 Oxford expedition recorded a progressive increase in regional metamorphism from east to west, suggesting that the western schists and gneisses are the highly metamorphosed representatives of the Hecla Hoek sediments. The observations of the 1933 Oxford expedition in northern Ny Friesland support the hypothesis of this gradual transition. The work of the Cambridge expeditions of 1930, 1932, 1938, and 1949 in the schists and gneisses of Finnlandveggen has shown overfolding and thrusting to the west, and the presence of several rock types which have not been recorded from the north. Here, and in the area to the south, the line of contact between the two series is covered by ice, but the Hecla Hoek sediments are exposed within two miles of the western schists, and neither series appears to show sign of change in metamorphic grade. Recent work, based on collections made by Oxford expeditions in Nordaustlandet, has shown that in that district the relatively unmetamorphosed Hecla Hoek series rests with apparent unconformity on a highly metamorphosed 'archaean' basement complex [6]. It has been suggested that this basement complex may be correlated with part of the western series of Ny Friesland, and that, in some areas at least, the boundary between the eastern and western series may be tectonic.

Although it is these areas of north-east Spitsbergen that have been visited by the majority of British expeditions, other parts of the islands have occasionally been studied. In 1927 Gino Watkins took a small party from Cambridge to Edgeøya. A Birmingham geological expedition visited the western part of Isfjorden in 1948, and in 1950 a party of two students, organized from London, began a geological survey in the northern part of Prins Karls Forland. Both these investigations, as well as those of the Oxford and Cambridge expeditions in 1949, were continued in the summer of 1951.

THE FUTURE

The *Norsk Polarinstitutt* at Oslo is responsible for the official Norwegian survey, and is actively engaged in many other fields of research; it is therefore increasingly important for British expeditions to plan carefully, so as not to duplicate or anticipate the long-term Government programme.

There is a considerable field in which useful investigations can take place. Geological and glaciological research holds the promise of results of fundamental importance, and the experience now accumulated by British expeditions provides a firm basis for continued investigations.

BIBLIOGRAPHY

ORVIN, A. K. *Norg. Svalbard- og Ishavs-undersøk. Skr.* No. 89, 1947.

Idem. Polar Rec., **6**, 179, 1951.

ROMANOVSKY, V. 'Spitzberg et la Sibérie du Nord.' Bibliothèque géographique, Paris. 1943.

RUDMOSE-BROWN, R. N. 'Spitsbergen.' Seeley, Service & Co. Ltd., London. 1920.

'The Place-Names of Svalbard.' *Skr. Svalb. og Ishavet.* No. 80, 1942.

REFERENCES

[1] CONWAY, W. M. 'No Man's Land,' p. 283. The University Press, Cambridge. 1906.

[2] SUMMERHAYES, V. S. and ELTON, C. S. *J. Ecol.*, **16**, 193, 1928.

[3] Spitsbergen Papers. Oxford University Press, London. Vol. I, 1925; Vol. II, 1929.

[4] MOSS, R. *Geogr. J.*, **92**, 211, 1938.

[5] GLEN, A. R. *Ibid.*, **98**, 65, 1941.

[6] SANDFORD, K. S. *Quart. J. geol. Soc. Lond.*, **105**, 461, 1949.

Some aspects of insecticide biochemistry

F. P. W. WINTERINGHAM

The economic importance of insecticides in protecting both growing crops and stored food needs no emphasis, but their widespread use for these purposes presents the biochemist with many problems. On the one hand there is the need to protect the consumer from any possible harmful effects due to residual insecticides, on the other there is the need for investigating the mode of action of insecticides as a prelude to finding new and better products by logical deduction, rather than by the empirical methods now often followed.

Estimates of the annual damage to world food by insects are unavoidably based largely upon guesswork. A United Nations survey [1] suggests that over the years 1937 to 1940 the mean weight of cereals available each year for world consumption would have been increased by about 5 per cent. had it not been for losses due to insect infestation. Whatever the reliability of this figure, it is certain that in food-importing countries like Britain the control of insects which attack growing crops and stocks of cereals is a matter of national importance. For this reason, there is an organized application of insecticides to infested crops and stored food products. Food is, therefore, liable to exposure to insecticidal chemicals during growth, storage, manufacture, and distribution; this raises several problems for the biochemist.

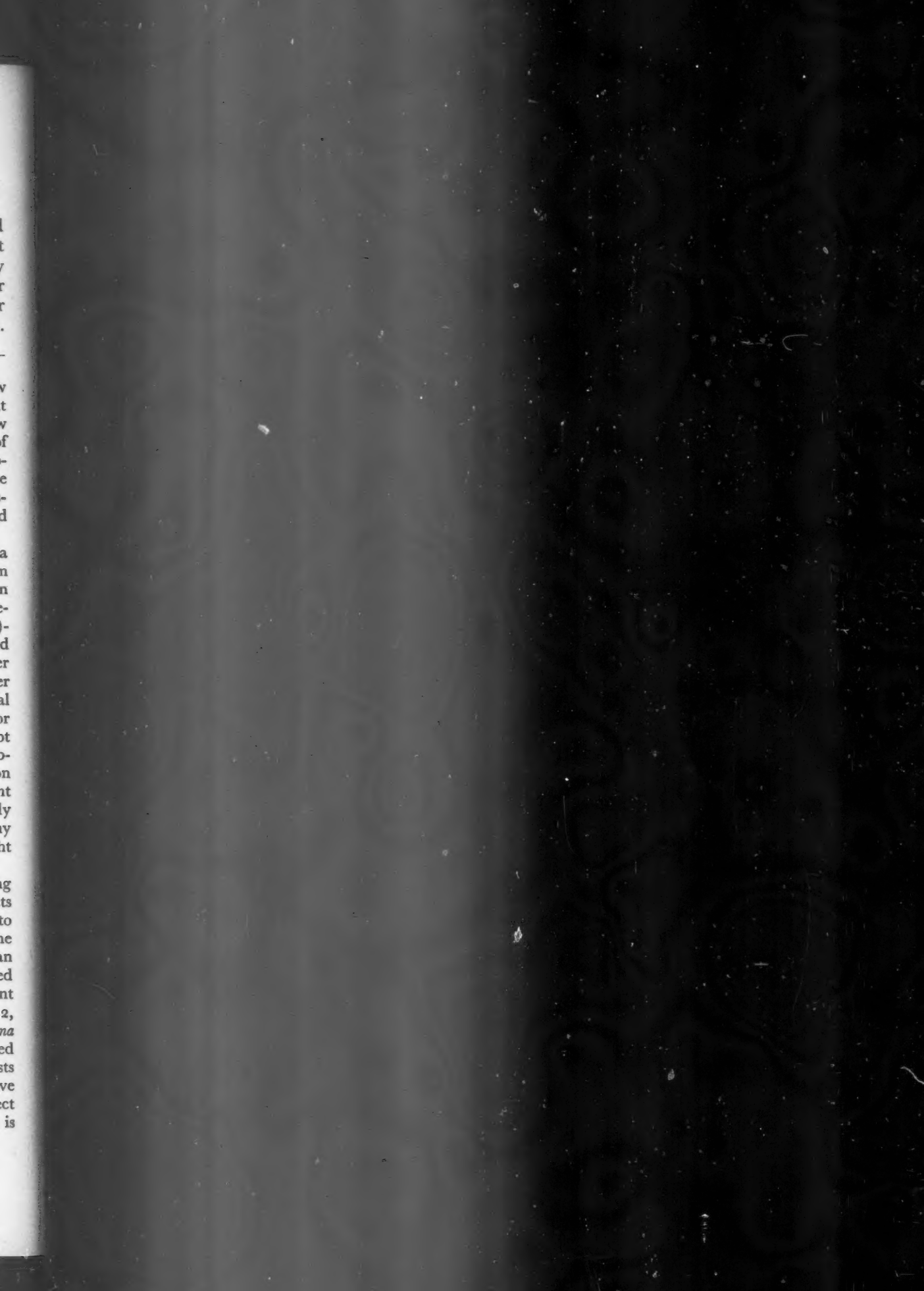
CONTAMINATION OF FOOD

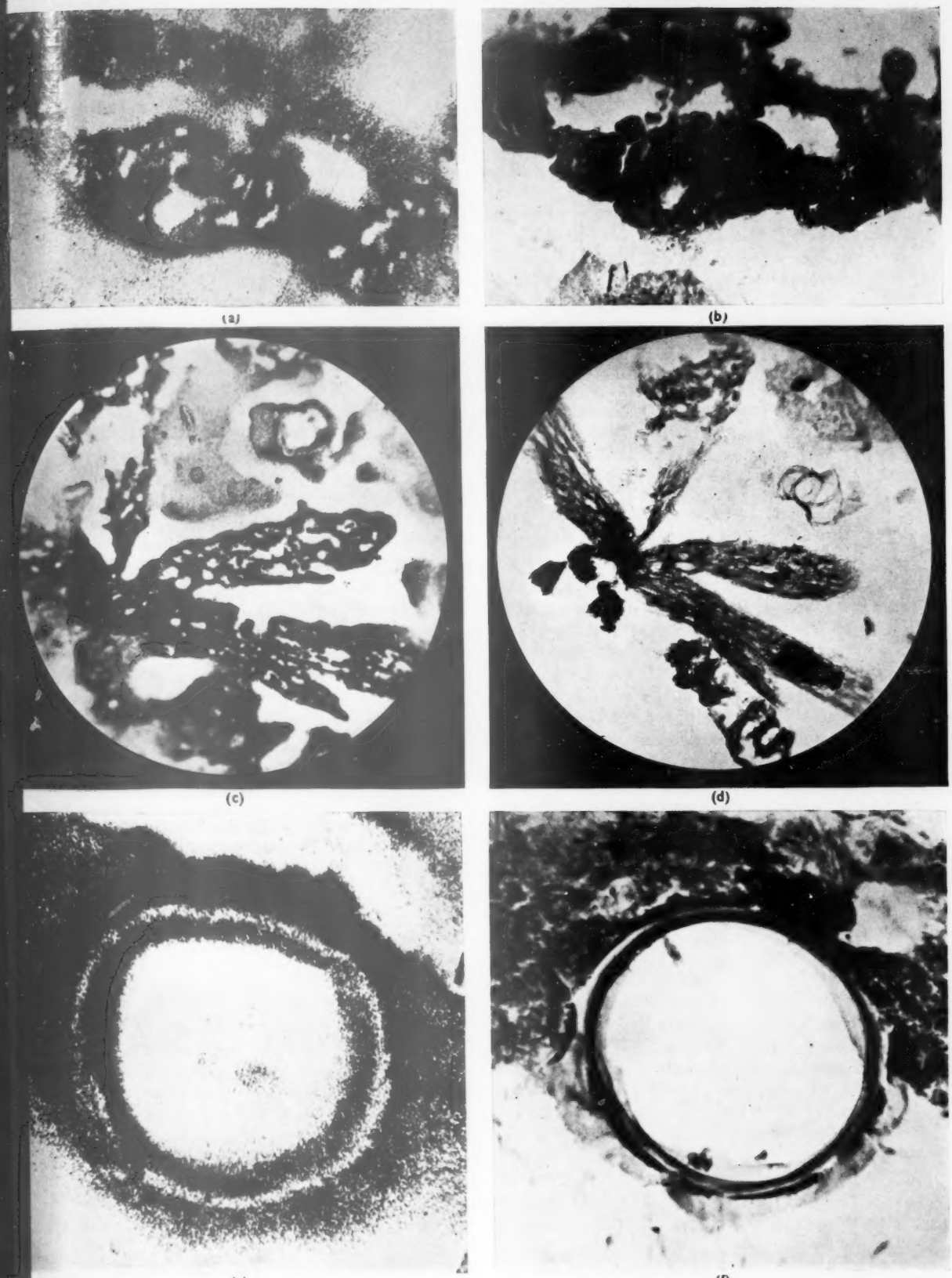
Most insecticides, including those applied as fumigants, are chemically reactive and biologically poisonous. They must, therefore, be selected and applied intelligently if the possibility of merely substituting one danger for another is to be avoided. One obvious hazard is to the men whose job it is to apply insecticides; some of the newer phosphorus-containing insecticides such as Parathion (O,O-diethyl-*p*-nitrophenyl-thiophosphate), and fumigants like hydrogen cyanide, methyl bromide, and carbon disulphide, are highly toxic to man. This hazard is relatively clear, and its control is largely a matter of simple precautions and training.

Traces of insecticides applied to infested foodstuffs are inevitably absorbed and usually retained by the food, and this may constitute a less obvious hazard. The concentrations are normally so low as to be of little toxicological or nutritional significance; it would, however, be very unwise to rely upon the level of concentration alone as the sole criterion of safety. The work on 'agenized' flour has clearly demonstrated this fact [2]. It is now known that when flour is 'improved' by treatment with 'agene' (nitrogen trichloride), even at the low concentrations used in milling practice, part of the methionine in the flour is converted to a substance which is highly toxic to some animals. The use of 'agene' is now being progressively discontinued in Britain and has completely ceased in the United States.

Britten and Fairing [3] have reported that a considerable proportion of residual insecticides in sprayed fruits reacts chemically with the fruit on cooking. For example, less than 5 per cent. of residual Methoxychlor (1, 1-bis (*p*-methoxyphenyl)-2, 2, 2-trichloroethane) was recovered unchanged after cooking peaches. Similarly, less than 40 per cent. of residual Parathion was recovered after canning apricots. The nature of the residual chemical products, and whether they are more or less toxic than the unchanged insecticides, are not yet known. The simplest approach to this problem would almost certainly be by the identification of the chemical products, because this might render unnecessary the empirical and costly method of extended animal feeding tests. In any case, such tests may fail to demonstrate very slight or delayed effects.

The problem of residual insecticides in growing crops differs from that in stored food products because growing crops are constantly exposed to the cleansing effects of sun, wind, and rain. The residual insecticide of products stored in bulk can escape only by slow vaporization into the limited air spaces within the material. The persistent insecticides DDT (1, 1-bis (*p*-chlorophenyl) 2, 2, 2-trichloroethane) and Gammexane (the *gamma* isomer of hexachlorocyclohexane) are widely used against domestic, warehouse, and agricultural pests as sprays and dusts. In some countries they have been mixed with grain in bulk to restrain insect development during prolonged storage. There is





IGURE 1 – *Autoradiographs* (a, c, e) *showing concentrations* (*black zones*) *of iodide in transverse sections* (*photomicrographs* b, d, f) *blow-fly larvae poisoned by exposure to methyl iodide labelled with* I^{131}. (a) *and* (b)*: Salivary gland* (× 270)*;* (c) *and* (d)*: bundle muscle tissue* (× 170)*;* (e) *and* (f)*: longitudinal tracheae* (× 650).

[Crown copyright reserved]

a chance, therefore, that residues will ultimately find their way into flour and bread. It is most unlikely that the average person would continuously consume bread or confectionery made solely from contaminated flour, since dilution almost invariably takes place at some stage before baking. This may not, however, apply to every person, and it is well established that both these insecticides tend to accumulate after being eaten, so that over long periods concentrations will build up in the body fat [4]. This accumulation may not normally be associated with detectable symptoms, but should the body have to draw on fat reserves, during illness for example, then acute symptoms might become manifest. In this problem, the toxicity of any insecticide decomposition-products formed in baking must also be considered.

For studying the fate of DDT under these conditions an analogue of DDT containing radioactive bromine has been used. In this way, insecticidal residues and their decomposition or metabolic products could be determined and identified by the use of radioactive tracer techniques [5]. When some wheat grain was deliberately contaminated with spray containing the radioactive insecticide it was found that about a quarter of the residual insecticide found its way into bread made from the milled wheat. About half of the residual insecticide in the crust was decomposed during baking into a substance which, under chromatographic separation, behaved as the benzophenone derivative. There is some evidence [6] that the benzophenone derivative of DDT is less toxic to mammals than unchanged DDT, in which case baking will reduce the toxicity of DDT-contaminated bread resulting, for example, from the use of DDT sprays or smokes in bakeries. The fate of Gammexane under the same conditions has not yet been studied. Meanwhile, until sufficient is known of the chemistry of these insecticides in relation to food, the inter-departmental insecticides organization of the (British) Agricultural Research Council has recommended as a safeguard that the concentrations of these insecticides in food should be restricted to the low levels of 7 parts per million and 2·5 parts per million, respectively.

When infested food products are fumigated, some of the absorbed fumigant cannot be recovered even by prolonged aeration, suggesting a chemical reaction with the food. Turtle [7] studied the absorption and retention of hydrogen cyanide by dried fruits under the normal conditions of fumigation. He found that some of the absorbed hydrogen cyanide combined with the reducing sugars in the fruit with the formation of cyanohydrins; he concluded that the toxicity of these substances to animals was of the same order as that of equivalent weights of free hydrogen cyanide. On the other hand, hydrogen cyanide is not a cumulative poison; part of sub-lethal doses is expelled through the lungs and part is rendered non-poisonous by conversion to thiocyanate. These facts, combined with the low concentrations involved, indicated that the risk in eating the fumigated fruit would be very slight. Turtle indeed consumed, without ill effects, an apparently alarming quantity of deliberately contaminated raisins.

In recent years, methyl bromide has been employed extensively in Britain, France, and the United States for fumigating infested wheat, maize, and other grain. Various workers [8–11] have studied the absorption and retention of this fumigant by different food products. Part of the absorbed methyl bromide was found to react chemically with cereal food products, principally with the protein constituents. After airing for short periods, nearly all the residual methyl bromide could be accounted for as water-soluble inorganic bromide. The analytical determination of inorganic bromide in foods is a simple matter, and the increase in the inorganic bromide content of the fumigated product has therefore been used as a measure of the magnitude of the chemically combined fumigant residue. At the concentration levels obtaining in the fumigated food (usually considerably less than 500 parts per million) the bromide is unlikely to be of any physiological or nutritional significance. In unfavourable circumstances this might not be the case, for the methyl groups must also be introduced simultaneously into the food, either as a simple product of hydrolysis such as methyl alcohol, or as some methylated derivative of one or more of the food constituents. It was, therefore, of some importance to study the chemical fate of this portion of the methyl bromide molecule. The conditions of methyl bromide fumigation in Britain, together with the invariable dilution of fumigated with unfumigated products, preclude any likelihood of nutritional or toxic effects. New products and conditions of fumigation have constantly to be considered, however, and possible effects have to be closely examined in the biochemical laboratory. Such might be the case with flour, for example, which, however, is not fumigated with methyl

bromide in Britain at present. Hermitte and Shellenberger [12] noticed an objectionable odour when flour which had been fumigated with methyl bromide was treated with alcoholic potash; no effect was obtained with unfumigated flour. Methyl bromide combines with methionine, with the formation of methyl methionine sulphonium bromide [13]; this sulphonium salt is decomposed by alkali with the liberation of the unpleasantly smelling dimethyl sulphide [14]. Methionine is an important amino-acid constituent of wheat protein, and it seemed certain that the formation of the sulphonium salt in the fumigated flour was responsible for the odour observed by Hermitte and Shellenberger. Moreover, Lewis [15] subsequently detected the liberation of dimethyl sulphide on adding alcoholic potash to gluten (wheat protein) which had been exposed to a high concentration of methyl bromide.

The next problem was to determine to what extent this and other reactions occurred in flour under the conditions of fumigation. The relatively low concentrations involved, and the chemical identity of some of the groups naturally present with those likely to be introduced by fumigation, made examination of the problem by conventional analysis impracticable. It has, however, been possible to study the general reactions involved by using methyl bromide labelled with radioactive carbon-14. Wholemeal wheat flour was exposed to the labelled fumigant under the normal conditions of fumigation, and was then aerated to remove the volatile unchanged methyl bromide. Samples of the gluten, starch, water-soluble, and ether-soluble fractions of the wheat were prepared. The carbon-14 content of these fractions was assayed radiometrically. This gave a specific measure of the extents to which the various fractions had reacted with the absorbed methyl bromide, since the radioactivity determined could have resulted only from the labelled fumigant. 87 per cent. of the total reaction (which was equivalent to 500 parts per million of residual fumigant) was accounted for in the gluten fraction of the wheat; 9 per cent. in the starch fraction; 3 per cent. in the water-soluble fraction, and 0·5 per cent. in the ether-soluble fraction, the last probably being due to lipoprotein, which is known to contain reactive thiol groups. The major groups involved in the protein reactions were determined as follows. Any sulphonium salt containing the group $C^*H_3.\overset{|}{S}^+.CH_3$ formed by the action of the labelled fumigant on the protein methionine can be decomposed by alkali, yielding the volatile dimethyl sulphide, one methyl group of which would be labelled. Thiomethoxy groups—$S.C^*H_3$ formed by the action of the labelled fumigant on protein thiol groups yield with alkalis the corresponding salts, which themselves decompose on acidification and liberate the volatile methyl mercaptan.

The thiomethoxy group of unchanged methionine does, in fact, behave in the same way, but in this case the resulting mercaptan is unlabelled, so that the two products may be distinguished. The mercaptan and sulphide can be isolated as the mercuric cyanide and mercuric chloride derivatives respectively, so that the radioactive carbon content of these derivatives is a direct measure of the thiomethoxy and sulphonium derivatives formed in the original protein. Methoxy groups —$O.C^*H_3$ could be formed, for example, by the esterification of free carboxylic acid groups of protein glutamic acid. These groups, together with the sulphur derivatives, all yield volatile methyl iodide on mild hydrolysis of the protein with hydriodic acid. The difference between the radiocarbon recovered as the mercury derivatives and that recovered as the methyl iodide was therefore an indirect measure of any methoxy groups formed during fumigation. In a similar manner, such groups as $\rangle N.C^*H_3$ were determined as methyl iodide by drastic treatment of the protein with hydriodic acid in the presence of ammonium iodide. The preliminary results indicated that 40 per cent. of the combined methyl bromide was present as sulphonium derivatives, 10 per cent. as thiomethoxy derivatives, and the remainder as methylated nitrogen derivatives, with some evidence for the formation of a small proportion of methoxy derivatives. These studies have enabled compounds likely to be formed during the fumigation of flour with methyl bromide to be synthesized in the laboratory, and examined for possible toxicity to animals.

MECHANISMS OF INSECTICIDAL ACTION

The fact that a given weight of a biological poison is ultimately able to affect a relatively enormous weight of animal tissue shows that the poison interferes with an essential link in a chain of vital processes. Frequently these links appear to be one or more of the enzyme systems of the living tissue, but in some cases other important factors, such as cell permeability, may be the primary link affected; this occurs in narcosis, for example. Again, some dusts which are insecticidal

in spite of their chemical inertness appear to exert their effects by destroying the insect's facility to conserve the minimum quantity of water essential for its life [16], and it is doubtful if any particular enzyme system is directly involved in such cases. It is reasonably certain, however, that many insecticides exert their effects through enzyme interference, even though the particular enzyme systems involved have not yet been identified; the study of insect enzyme systems is, in fact, a comparatively unexplored field. It is known that hydrogen cyanide blocks the insect's respiratory mechanism by the inhibition of cytochrome oxidase. The irreversible combination of methyl bromide with thiol groups in living insect tissues has been demonstrated; this in turn must inhibit many essential enzymes whose function is known to depend upon the integrity of free thiol groups. Some of the newer phosphorus-containing insecticides like Parathion inhibit insect acetylcholinesterase, and the degree of cholinesterase inhibition *in vitro* has been very closely correlated with the degree of insecticidal action [17].

The mode of action of DDT and of the pyrethrins is by no means so clear. The excessive motor activity, and paralysis, the symptoms to which they respectively give rise, strongly suggest some profound, but quite different, interference with the muscular and nervous physiology. An interesting mode of insecticidal action has been suggested by Slade [18] for Gammexane. It was believed that this insecticide possessed a molecular configuration sterically similar to the B-vitamin *meso*-inositol, and might therefore gain access to some vital site through a biological process which was unable to discriminate between the two molecules. Although evidence was forthcoming both for and against this hypothesis, the fact that the *gamma* isomer alone was relatively highly insecticidal certainly emphasizes the importance of molecular shape in some mechanisms of insecticidal action. It is the purpose of the following paragraphs to illustrate the present biochemical approach to this field.

Three ways of approach may be recognized. In order to be effective, an enzyme poison must reach the sensitive cells or sites of action in a toxic form and in sufficient concentration. The dose or weight of insecticide absorbed by a given weight of tissue, as distinct from the weight applied externally as a spray or fumigant, must be known. The relation between these two weights varies considerably from insect to insect, and according to the formulation of the insecticide, physical conditions, and so on, a fact which is sometimes overlooked in studies of the mode of action of these substances. Clearly, in attempting to correlate insecticidal action with chemical structure, different chemicals should be compared at similar molar concentrations in the insect tissue or in enzyme-active preparations. Comparison merely at similar levels of application is likely to yield differences not due at all to differences in structure but perhaps only to purely physical factors such as cuticle permeability, 'wetting' properties of the insecticidal formulation, and so on. First, therefore, the absorption and distribution of the insecticide by the insect must be studied quantitatively.

Secondly, insecticidal action may be due to some metabolite of the insecticide rather than to the insecticide itself; its action is in any case likely to involve a chemical change at the site of action. Chemically inert substances are rarely toxic. Conversely, a defence mechanism may be in operation which depends upon the degradation or synthesis of the absorbed insecticide to some innocuous derivative. To understand any of these events the chemical fate of the insecticide itself must be studied.

Thirdly, it is necessary to study the disturbances in the normal physiology and metabolism of the living insect which give rise to the observed and ultimately fatal symptoms. In this respect the small size of the insect presents difficulties. Tedious dissection yields only minute quantities of material. It would be difficult, too, to assess physiological changes in the insect corresponding to those which are so useful in toxicity studies in animals—for example, variations in body temperature, cardiac stimulation, and sedative action. One has generally to rely upon gross symptoms, which themselves may be purely secondary effects, such as obvious changes in respiration rate and lack of response to mechanical stimuli. Although death of the insect is the ultimate objective in using these substances in practice, it is probably the least useful biological response in determining mode of action.

When all these approaches indicate a single pattern which accounts for the observed biological properties of the insecticide and its chemical relatives, then its mode of action can be said to be fairly well understood.

The development of radioactive tracer and paper chromatography techniques in recent years has placed powerful new research tools in the hands of the biochemist. This applies particularly to the study of the absorption, distribution, and metabolism of insecticides by the insect. An

example is a study of the distribution of radioactive water-soluble iodide liberated in the tissues of blow-flies poisoned by exposure to labelled methyl iodide. Blow-fly larvae were poisoned by exposure to methyl iodide labelled with radioactive iodine-131. The tissues of these larvae were dehydrated by a freeze-drying technique to avoid interfering with the natural distribution of the absorbed fumigant. Sections of the larvae cut with a microtome were then coated in the dark with a micron-thick photographic emulsion [19]. The histological distribution of the radio-iodide, liberated *in vivo* during poisoning, photographed itself as a result of the beta-particle emission of the radioactive isotope. After fixing and developing, the emulsion and section were separated. The section was stained and then matched with the autoradiograph under a microscope. Figure 1 shows some autoradiographs made in this manner, together with photomicrographs of the corresponding sections.

Flies breeding in areas subjected to repeated DDT treatment tend to become resistant to it. This has become so serious in some parts of the world that the use of DDT has been abandoned. Recent work in Britain and in the United States has shown that the resistant fly is capable of degrading the absorbed DDT to a non-toxic ethylene derivative, probably by enzyme action [20]. For the purpose of studying this problem, a radioactive bromine analogue of DDT was injected into individual susceptible and individual resistant adult flies. After various intervals, the insecticide and any metabolic degradation products were extracted and then separated chromatographically. In this method, the metabolites became separated in concentrated zones at characteristic proportional distances (determined by their R_f values) along a strip of impregnated paper [21]. Being radioactive, the separated zones could be located and estimated radiometrically by plotting the observed radioactivity against distance along the strip. The area below each peak of radioactivity, the position of which is characteristic for a given derivative, is proportional to the weight of derivative present. Figure 2 illustrates the application of the method to a DDT-susceptible and to a DDT-resistant housefly, which were examined twenty-four hours after injecting 0·6 microgram of the labelled insecticide. It will be seen that more than half of the insecticide has been degraded to the ethylene derivative by the resistant fly, while the insecticide was recovered unchanged from the susceptible one.

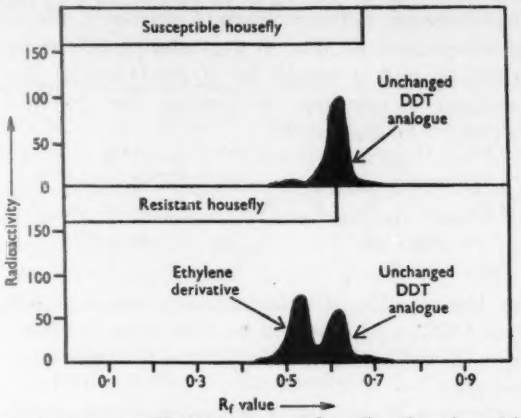
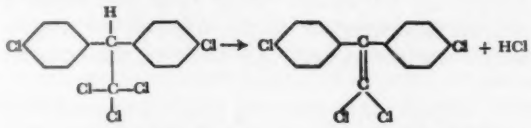
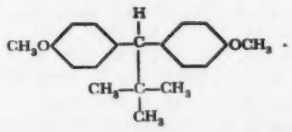


FIGURE 2 – *Chromatograms of radioactive insecticide metabolites recovered from houseflies.*

Many of the analogues and derivatives of DDT possess insecticidal properties very similar to those of the parent compound. If the resistance of houseflies is indeed due to their ability to dehydrohalogenate the DDT molecule, then it should be possible to predict a DDT-type insecticide against which this mechanism would be ineffective. At first sight this is merely a question of selecting a compound which cannot undergo dehydrohalogenation, which in the case of DDT proceeds as follows:

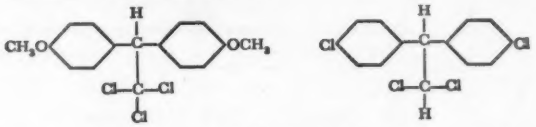


The DDT-type compounds which possess insecticidal properties can, however, be readily dehydrohalogenated by alkali, and Martin and Wain have in fact advanced this property as a prerequisite of insecticidal action [22]. If this hypothesis be correct, it is of interest to note that, in resistant flies at least, the sites of metabolism and insecticidal action must be quite different. The compound 1, 1-bis-(*p*-methoxyphenyl)-2, 2-dimethyl propane cannot undergo dehydrohalogenation and has the structure:



It has been reported to possess insecticidal properties against the housefly, but DDT-resistant houseflies have been reported to be resistant to this compound also [23]. Nevertheless, it is likely

that there are different kinds of resistance, not all of which may be due to degradation of the insecticide, and it would be of fundamental and practical importance to pursue the problem further. The insecticides



are less capable of dehydrohalogenation *in vitro* than DDT, and it would be interesting to determine the tolerance of resistant flies for these compounds.

Acetylcholinesterase is the enzyme responsible for the control, by hydrolysis, of the acetylcholine which is liberated in tissue as a mediator of nerve impulses. If this important enzyme is inhibited, acetylcholine accumulates above the natural levels of tissue concentration and then behaves as a powerful poison. Metcalf and March [17] have studied the inhibition of this enzyme by a range of organic phosphates, some of which are used for spraying infested crops. They have demonstrated a close correlation between the toxic action and the degree of inhibition of preparations of the enzyme from houseflies, honey bees, and mice. For example, all three enzyme species were inhibited by Parathion, while only the housefly enzyme was sensitive to the *iso*propyl analogue, which was correspondingly toxic to the housefly but relatively non-toxic to the honey bee and the mouse. The data suggest that there are sensitive differences in the structures of the protein moieties of these enzyme species, so that the molecular configuration of the *iso*propyl analogue permits access to the sensitive link of the one enzyme system only. As Metcalf and March point out, there seems to be no reason why this remarkable specificity should not be exploited by the selection or development of a Parathion-type insecticide highly toxic to the pest but comparatively innocuous in other respects, a property unfortunately lacking in Parathion itself.

A considerable effort is being expended in the routine testing of compound after compound from the organic laboratory shelf in the hope of turning up a new potent insecticide. Some of this effort would be more fruitfully expended in studying further some of the existing poisons, of which there is no shortage. This point is illustrated by research on the natural pyrethrins, which probably represent one of the nearest approaches to the ideal insecticide. As a result of patient work, largely by Harper, Laforge, Staudinger, and their colleagues, the complex structure of the pyrethrins has been elucidated and the synthesis of an effective homologue (*dl*-2-allyl-4-hydroxy-3-methyl-2-cyclopenten-1-one esterified with the chrysanthemum monocarboxylic acids) has become a commercial proposition. It is unlikely that this compound would ever have been found on the laboratory shelf.

REFERENCES

[1] United Nations Food and Agriculture Organization. *Proceedings of the International Meeting on the Infestation of Foodstuffs*, London, p. 6, 1947.

[2] Bentley, H. R., McDermott, E. E., Moran, T., Pace, J., and Whitehead, J. K. *Proc. Roy. Soc. B.*, **137**, 888, 402, 1950.

[3] Britten, W. A. and Fairing, J. D. *J. Assoc. Off. Agric. Chemists*, Washington, **33**, 3, 599, 1950.

[4] Bryson, M. J., Draper, C. I., Harris, J. R., Biddulph, C., Greenwood, D. A., Harris, L. E., Binns, W., Miner, M. L., and Madsen, L. L. *Symposia on Agric. control Chem.*, Washington, p. 232, 1950.

[5] Winteringham, F. P. W., Harrison, A., Jones, C. R., McGirr, J. L., and Templeton, W. H. *J. Sci. Food Agric.*, **1**, 7, 214, 1950.

[6] Browning, H. C., Fraser, F. C., Shapiro, S. K., Glickman, I., and Dubrule, M. *Canad. J. Res.*, **26**, 5, 282, 1948.

[7] Turtle, E. E. 'Studies in the Retention of Hydrogen Cyanide by Certain Products on Fumigation.' London University, Ph.D. thesis, 1941.

[8] Roehm, L. S., Shrader, S. A., and Stenger, V. A. *Cereal Chem.*, **19**, 2, 235, 1942.

[9] Lubatti, O. F. and Harrison, A. *J. Soc. Chem. Ind.*, **63**, 353, 1944.

[10] Winteringham, F. P. W. and Harrison, A. *Ibid.*, **65**, 140, 1946.

[11] Lewis, S. E. and Eccleston, K. *Ibid.*, **65**, 149, 1946.

[12] Hermitte, R. J. J. and Shellenberger, J. A. *Cereal Chem.*, **24**, 449, 1947.

[13] Toennies, G. and Kolb, J. J. *J. Amer. Chem. Soc.*, **67**, 849, 1945.

[14] Crane, C. W. and Rydon, H. N. *J. Chem. Soc.*, 766, 1947.

[15] Lewis, S. E. Personal communication.

[16] Wigglesworth, V. B. *J. Exp. Biol.*, **21**, 3, 97, 1945.

[17] Metcalf, R. L. and March, R. B. *J. econ. Ent.*, **43**, 5, 670, 1950.

[18] Slade, R. E. *Chem. and Ind.*, **40**, 314, 1945.

[19] Winteringham, F. P. W., Harrison, A., and Hammond, J. H. *Nature*, **165**, 149, 1950.

[20] Winteringham, F. P. W., Loveday, P. M., and Harrison, A. *Ibid.*, **167**, 106, 1951.

[21] Winteringham, F. P. W., Harrison, A., and Bridges, R. G. *Ibid.*, **166**, 999, 1950.

[22] Martin, H. and Wain, R. L. *Ibid.*, **154**, 512, 1944.

[23] Brown, H. D. and Rogers, E. F. *J. Amer. Chem. Soc.*, **72**, 1864, 1950.

Fibres from aromatic polyesters

J. R. WHINFIELD

Fundamental research on artificial high polymers was not initiated until long after they were firmly established in daily use. It has now, however, proved very valuable, most particularly in establishing relationships between certain physical and chemical characteristics of high polymers and their practical usefulness. Theory is now sufficiently advanced to provide a logical route to polymers possessing preselected properties; a notable achievement in this field is the development of polymerized ethylene terephthalate as a new synthetic textile.

The great but pontifical Berzelius defined polymerization as a special instance of isomerism, and it was not until a century later that his definition was challenged. Then, in 1928, Carothers and his co-workers published the first of a series of papers, which eventually extended over eight years, under the title 'Studies in Polymerization and Ring Formation' [1]. In these papers, describing research aimed at 'the synthesis of giant molecules by strictly rational methods,' experiment and theory were closely linked. In the first paper of the series examples were quoted to show that 'whatever the term polymer may now mean it does not mean precisely what Berzelius intended, and the conditions which he set up are not sufficient to define it.' In a later paper it was pointed out that 'it is more practical and useful . . . to define polymerization as any chemical combination of a number of similar molecules to form a single molecule.' The term co-polymerization has since been introduced to denote cases in which more than one molecular species is involved in the combination.

For a molecule to be capable of self-condensation, two mutually reactive groups must be present. If the structure is such as to preclude the formation of 5- or 6-membered rings, the reaction proceeds inter-molecularly and linear polymers result. Thus ω-hydroxydecanoic acid condenses with itself on heating to yield a polyester represented by the formula

$$HO[—(CH_2)_9—CO—O]_n(CH_2)_9COOH.$$

Such, in its essentials, was the simple generalization advanced by Carothers, who pointed out the immense possibilities of this field of research by saying that 'the number of possible types of condensation polymers is practically unlimited.' The scope of this method of synthesis is even further extended by using two compounds of the type x—R′—x and y—R″—y in which the groups x and y are mutually active.

The work of Carothers on condensation polymerization rested fundamentally on the theory that large polymers consist essentially of enormously long chains built up from repeating units linked by primary valencies. This theory, representing as it did a crystallization of several lines of contemporary thought, exercised an immediate effect on the whole field of polymer chemistry; in its light, the general problem of the relation between the molecular structure of polymers and their distinguishing physical characteristics could at last be attacked. Within a few years the original theory was refined and extended to embrace cross-linking and chain-branching; the synthesis of macromolecules was studied from the standpoint of reaction kinetics, and their properties were investigated in terms of thermodynamics. As an outcome of this sudden activity, certain general lines of research were clearly seen to be likely to yield particularly valuable results; they were concerned with such important questions as the lengths of the long molecules, the shapes which they assume, their flexibility or rigidity, and their dispositions with respect to each other.

Carothers, however, was among the first to perceive that as a further consequence of this theory there was now open to the chemist a logical rather than an empirical path to the making of new polymers, the constitution of which would be rendered certain by their methods of synthesis.

In an early study of condensation-polymerization, Carothers investigated the reaction between phthalic anhydride and ethylene glycol and obtained various amorphous resins. He also described a number of polyesters of the type

$$—CO—(CH_2)_m—CO—O(CH_2)_n—O—$$

such as, for example, those in which m is 2, 4, or 8, and n is 2, 3, 6, or 10. All these proved to be micro-crystalline solids, with melting-points not exceeding 107° C.

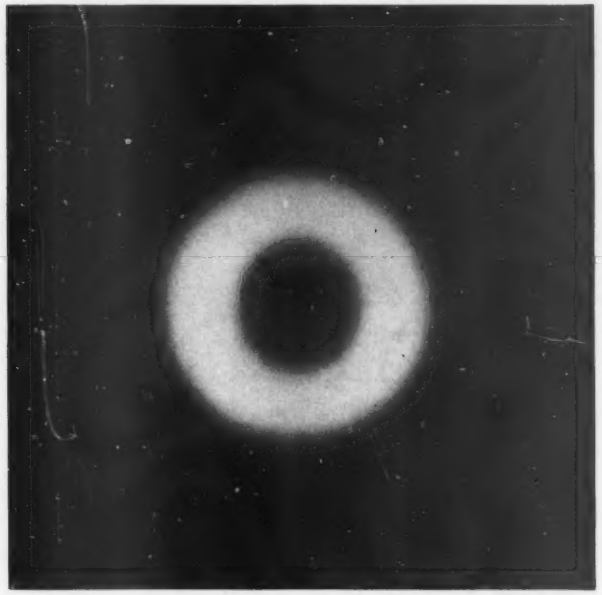


FIGURE 1 – *X-ray diffraction pattern, photographed on a cylindrical film using CuKα radiation, of spun filaments of Terylene. This material is non-crystalline and unorientated.*

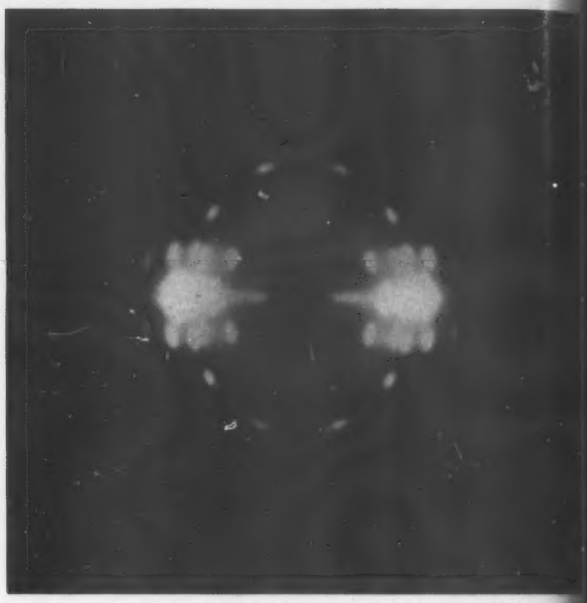


FIGURE 2 – *X-ray diffraction pattern for drawn Terylene filaments, taken under same conditions as for filaments in figure 1. This material is crystalline and well orientated.*

(Photographs by courtesy of Mr C. W. Bunn)

He went on to demonstrate the wide scope of his condensation-polymerization reactions by preparing a very large number of new polymers involving a variety of functional groups. For the most part, they were derived from bi-functional compounds in which the active groups were separated by simple polymethylene chains. All these polymers proved to be micro-crystalline, but, as at first prepared, none had molecular weights in excess of 5000, and all were lacking in the strength and toughness generally associated with a state of high polymerization. He therefore sought and found means of greatly increasing the degree of polymerization. Although this is now achieved readily enough, even on an industrial scale, the problem at first seemed so difficult that attempts to solve it demanded the inspiration of a complete faith in the essential correctness of the underlying theory. In the event, theory was completely justified. Polymers of low molecular weight were soft and brittle waxes or dusty powders; those of high molecular weight—which Carothers called super-polymers—were hard and horny, possessing the anticipated qualities of strength and toughness.

The first hint that these super-polymers were fibre-forming did not come until the twelfth of the series of papers: 'The most remarkable property of the super-polyesters is their capacity to be drawn out into very strong, pliable, highly orientated fibres.' This property was subsequently investigated in some detail. Continuous filaments were obtained from the molten polymer 'by touching it with a stirring rod and drawing the rod away.' X-ray analysis showed the resulting filaments to be unorientated. The process known as 'cold-drawing' was first mentioned in connection with the polyester derived from hexamethylene dicarboxylic acid and trimethylene glycol. Of this polymer it was reported that 'if stress is applied to a cylindrical sample of the opaque unorientated 3-16-ω-polyester at room temperature or at a slightly elevated temperature, instead of breaking apart it separates into two sections joined by a thinner section of the transparent orientated fibre. As pulling is continued this transparent section grows at the expense of the unorientated section until the latter is exhausted.'

Of the micro-crystalline condensation polymers investigated by Carothers, only the polyamides—of which nylon is representative—possessed sufficiently high melting-points to enable them to be made into useful textile fibres.

The observation that polymers possessing the dual character of being both micro-crystalline and of high molecular weight were capable of being drawn into fibres was not clearly predictable from contemporary theory, although it was known from X-ray analysis that natural fibres such as silk,

wool, and cotton possessed elements of micro-crystallinity and were orientated along their axes. The belief gradually gained ground, however, that fibre-forming polymers were crystalline and that, for some reason then not clearly understood, this property was especially significant. The resinous non-crystalline character of ethylene phthalate, in contrast with the micro-crystalline and fibre-forming properties of ethylene succinate and its homologues, lent support to this view, and also suggested very strongly that some degree of molecular symmetry was the determining factor in the crystallinity of high polymers. There was, therefore, good reason to believe that if ethylene terephthalate could be obtained in a highly polymerized form it would, on account of its symmetry, be crystalline, and would be capable of forming fibres. Accordingly, it was decided to make a determined effort to synthesize this particular polymer [2, 3].

Benzene forms three dicarboxylic acids—phthalic (ortho), *iso*phthalic (meta), and terephthalic (para). Of these, only phthalic acid has hitherto been manufactured industrially, though both the others have long been accessible for laboratory work. It is, therefore, very surprising that ethylene phthalate was described for the first time only in 1928, and that ethylene *iso*phthalate and terephthalate were not described, despite their simplicity, until 1941. Terephthalic acid itself is a rather intractable substance. It is sparingly soluble in most solvents, and sublimes without melting at about 300° C. Like *iso*phthalic acid, it forms a polymerized anhydride, an observation made as long ago as 1913 but apparently subsequently overlooked [4]. It yields simple esters without difficulty, but the conditions necessary for the production of polyesters of high molecular weight are exacting, and all side-reactions must be avoided or a discoloured product will result; such discoloration, typical of many aromatic substances under severe reaction conditions, is virtually impossible to remove.

Even if the molecular weight could be built up to that known to be necessary for formation of strong fibres, and side-reactions were eliminated, it was by no means certain that a useful product would result. The melting-point of the polymer might prove to be so low, as in the case of the aliphatic polyesters, as to preclude its practical application. Its stability was in grave doubt, for the ester linkage in the main chain might be easily severed in the hydrolytic conditions encountered in the ordinary treatment of textiles. These and other considerations at first weighed rather heavily against the prospect of making a satisfactory fibre from ethylene terephthalate.

Terephthalic acid reacts slowly with ethylene glycol at about 200° C to yield *bis*-hydroxethyl terephthalate as the primary product; on further heating this condenses with itself, with elimination of glycol. The condensation is progressive, and under appropriate conditions it is possible to obtain ethylene terephthalate polymers of high molecular weight. A more convenient method, however, is to replace the free acid by its dimethyl ester, a crystalline substance which can readily be obtained in a state of high purity. Under the influence of an alkaline ester-interchange catalyst, the dimethyl ester reacts with glycol with elimination of methanol, the polycondensation reaction then proceeding as before.

The progress of the reaction is accompanied by a steady increase in the viscosity of the molten polymer, and this eventually reaches a very high value (of the order of 3000 poises at 280° C). The melt is then capable of yielding filaments which can be drawn after the manner described by Carothers. The physical changes in the polymer associated with these processes are extremely complex. The extruded filaments are transparent and amorphous, and yield the X-ray diffraction picture shown in figure 1. Cold-drawing brings about both the actual formation of crystallites and their alignment in a direction roughly parallel to the fibre axis. The cold-drawn fibres exhibit the characteristic X-ray diffraction pattern shown in figure 2.

The undrawn filaments are amorphous, because, being very fine, they cool extremely rapidly, and the long molecules become frozen in the disordered state in which they are present in the melt. These amorphous filaments have a density in the region of 1·33 g/cm^3, but their coefficient of expansion increases somewhat sharply at a temperature of about 80° C (the so-called second-order transition temperature), and when heated much above this point they crystallize. Under these circumstances crystallization is accompanied by an increase in density (to approximately 1·38 g/cm^3) and the filaments become opaque and brittle. This is the form in which the polymer is obtained in the massive state when the melt is slowly cooled; it is crystalline, but the crystallites are completely unorientated.

The term cold-drawing as applied to fibres of ethylene terephthalate is not strictly accurate, and requires some further explanation. In practice,

the process is carried out at a temperature above 80° C, that is to say, above the second-order transition temperature of the material; only when this temperature is reached is there any real freedom of molecular movement in the amorphous phase. In consequence, drawing at an elevated temperature is accomplished with lower stresses, and the process is more amenable to control. The second-order transition temperature of nylon is below 40° C, and the necessity for the application of heat at the drawing stage does not therefore arise in this case.

The tensile strength of the drawn fibres is in the range of 50–70 kg/mm², and they rupture only after elongating by some 10–25 per cent. of their original length. They show a high recovery from moderate strain, and a high initial Young's modulus. Thus from the point of view of their use as textile fibres they possess an interesting and favourable combination of physical and mechanical properties which are, within limits, capable of variation by adjustment of the conditions under which they are produced.

In their chemical properties and behaviour the fibres display several features of both practical significance and theoretical interest. As already mentioned, the question of their resistance to hydrolysis gave rise to initial anxiety. This resistance proved to be adequate for all practical purposes; towards acids, indeed, it is extremely high. Under relatively severe conditions of alkaline hydrolysis the fibres are attacked at the surface, and their diameter is progressively reduced. There is no random hydrolysis of ester linkages, and the residue does not at any stage suffer diminution in molecular weight or tenacity. This curious behaviour is believed to be unique among fibres, and the fact that, under any given set of conditions, the rate of attack, when related to the surface area, is a linear function of time, has been adduced as evidence that there is no differentiation between the structure of the surface layers and the interior of the fibres [5].

The behaviour of the fibres towards concentrated aqueous ammonia is, however, very different. On treatment with this reagent, even at room temperature, they slowly diminish in tenacity, and this diminution is related to a reduction in molecular weight; there is no appreciable loss of substance—at least until the process is far advanced—and the reaction may be regarded as somewhat analogous to the tendering of cotton by acids. The actual rupture of the ester linkages, however, occurs through amidation rather than hydrolysis, and is thus accompanied by a gradual increase in the nitrogen content of the material so treated. Prolonged exposure of the fibres to light of high intensity also results in degradation, which is marked by loss in tenacity and development of free carboxyl groups.

All these physical and chemical properties are a reflection of the molecular architecture of the fibres. It was earlier pointed out that the fibre-forming properties of ethylene terephthalate were predictable, but among the properties of the fibres themselves their high melting-point is the one of cardinal importance. It must be admitted, however, that this property was not predictable, nor can any entirely satisfactory theoretical explanation be offered now. This is, perhaps, not particularly surprising, since the factors which determine the melting-points of even simple compounds are still not well understood. It has, however, been shown that a high melting-point is characteristic of symmetrical glycol esters of aromatic dicarboxylic acids in general, and that it seems to be in some way associated with the rigidity of the ring structure and its attached carbon atoms, which limits the number of bonds in a given chain-length about which rotation can occur. A large number of such polyesters have been described by Hill and Walker [6], who point out several interesting relationships between their structures, melting-points, and other properties.

The investigation of the preparation and properties of polymerized ethylene terephthalate indicated that as a synthetic textile it ranked in the same class as nylon. Accordingly, plans are now being made for its large-scale production in Britain under the name of Terylene. This British-discovered fibre is also under manufacture in the U.S.A., where it is called Dacron. Its full uses have yet to be investigated, but certain fields of application are already clear.

REFERENCES

[1] Carothers, W. H. 'High Polymers,' Vol. I. Inter-Science Publishers Inc. New York. 1940.

[2] British Patent 578,079. 1941.

[3] Whinfield, J. R. *Nature*, **158**, 930, 1946.

[4] Bucher, J. E. and Slade, W. C. *J. Amer. Chem. Soc.*, **31**, 1319, 1909.

[5] Waters, E. *J. Soc. Dy. Col., Bradford*, **66**, 609, 1950.

[6] Hill, R. and Walker, E. E. *J. Polymer Sci.*, **3**, 609, 1948.

Colour vision: a retrospect

W. S. STILES

The study of the perception of colour has long proved of particular fascination to the inquiring mind; the problem is complicated by the difficulty of distinguishing between objective and subjective effects. Until recently, specialists in this field were rare, and it is interesting that much of our present knowledge of colour vision is due to the experiments and observations of men better known for their researches in other fields. Among them may be mentioned Boyle, Newton, Goethe, Young, von Helmholtz, Clerk Maxwell, and Rayleigh.

Though Robert Boyle (1627–91), in his *Experiments and Considerations touching Colours*, published in 1664, had recognized that colour is subjective—a characteristic sensation produced as a rule by the action of light on the eye—it was Isaac Newton (1642–1727) who took the indispensable first step towards a proper understanding of colour vision, namely the analysis of the physical stimulus into its simple constituents. In 1666 Newton purchased a glass prism and began the series of experiments and penetrating deductions by which he showed 'Light . . . to be not similar or homogeneal but consisting of difform rays some of which are more refrangible than others,' and 'Colors . . . to be not Qualifications of Light derived from Refraction of natural Bodies (as 'tis generally believed) but Original and Connate properties which in divers rays are divers.'

For the theory of colour vision, Newton's study of the composition of colours, or additive colour-mixing as we should now say, had an importance equal to that of the physical analysis of white light. He showed that some primary colours (to him these meant simply colours produced by monochromatic stimuli) appear identical with mixtures of other primary colours, and that 'all colours of the Universe made by light and not dependent on the power of the imagination' are either primary or mixtures of primaries. He represented all these non-imaginary colours by points in a plane diagram—'Newton's colour circle'—and he gave a geometrical construction for determining the colour of any particular mixture of primaries. Newton divided his colour circle (figure 1) into sectors, which were assumed to correspond in arc-length to the quantities of the seven main colours in the spectrum of the white light represented by the centre of the circle. To obtain the position of the point corresponding to a mixture of primary colours, small circles were to be drawn centred on the mid-points of the appropriate primary arcs, the area of each circle to correspond to the quantity of that colour in the proposed mixture. With these little circles considered as masses proportional to size, their centre of gravity in the diagram had then to be found. The position of this point defined the colour of the mixture. The sector in which the centre of gravity was situated, and the nearness to one or other radial boundary, decided the hue, while the distance from the centre decided the departure from whiteness. 'This Rule,' Newton wrote, 'I conceive accurate enough for practice, though not mathematically accurate.'

There is no significant contribution to the theory of colour vision to record in the hundred years following Newton's work. This period of quiescence ended with a violent attack on Newton's views on colour by Johann Wolfgang von Goethe (1749–1832). While pre-eminently a man of letters, Goethe was also a keen observer of Nature. When he turned his attention to the theory of colours, he made, like Newton, experiments with a prism. For Goethe, however, the most significant observation, the *Urphänomen*, on which his theory of colour was to be based, was the appearance of coloured fringes at any boundary separating white and black areas when viewed through a prism placed in front of the eye and suitably oriented. These boundary colours (figure 2), which Goethe may well be said to have discovered, are readily understood on Newton's view. There are two sets of them, depending on whether the base of the prism is on the white or the black side of the boundary. In the former case they arise, starting from the white area and moving to the black, by the removal from white light of first the spectral red, then the red and yellow, then the red, yellow, and green, and so on. With the prism turned the other way, the spectral colours are removed in the reverse order. Goethe's preoccupation with boundary colours led him to the fundamental principle of his colour theory: that colours owe their origin

to darkness as well as to light. It is possible to mix boundary colours by narrowing down a black or white strip until the fringe systems at the strip edges overlap, and to produce in this way all possible colours. The symmetry of this method of approach appealed strongly to Goethe, but while it remains interesting, it contributed little to subsequent advances.

A major scientific theory can seldom have received so brief and casual an introduction from its originator as that given by Thomas Young (1773–1829) to the trichromatic theory of colour vision. It is all contained in a brief passage in Young's Bakerian Lecture to the Royal Society in 1801. After quoting from Newton's *Opticks* the general conception that the spectral colours incident on the retina of the eye excite vibrations of different size which run along the capillaments of the optic nerve to the brain, Young gives his theory in the following words:

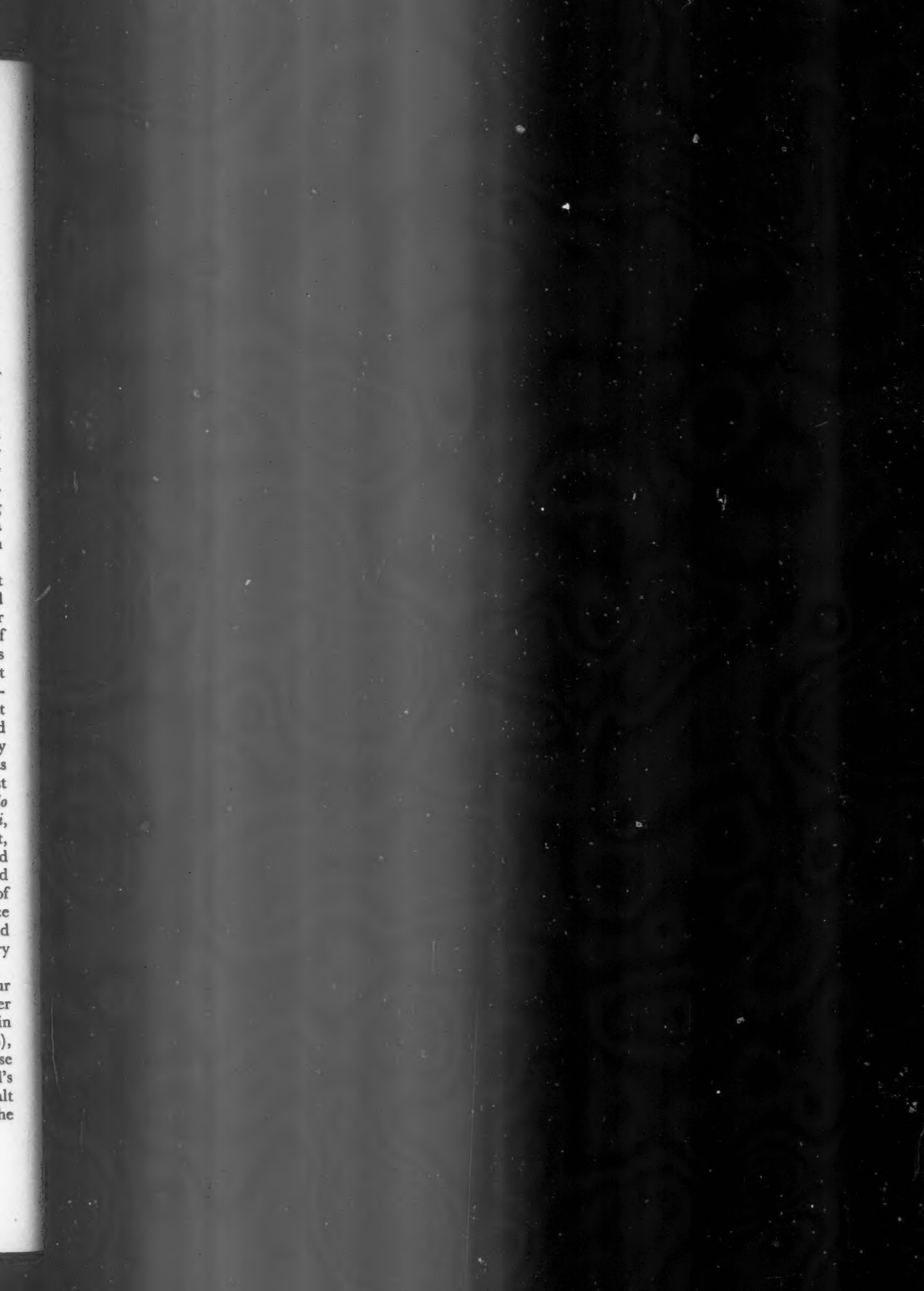
'Now, as it is almost impossible to conceive each sensitive point of the retina to contain an infinite number of particles, each capable of vibrating in perfect unison with every possible undulation, it becomes necessary to suppose the number limited; for instance, to the three principal colours, red, yellow, and blue, of which the undulations are related in magnitude nearly as the numbers 8, 7, and 6; and that each of the particles is capable of being put in motion less or more forcibly, by undulations differing less or more from a perfect unison; for instance, the undulations of green light, being nearly in the ratio 6½, will affect equally the particles in unison with yellow and blue, and produce the same effect as a light composed of those two species; and each sensitive filament of the nerve may consist of three portions, one for each principal colour.'

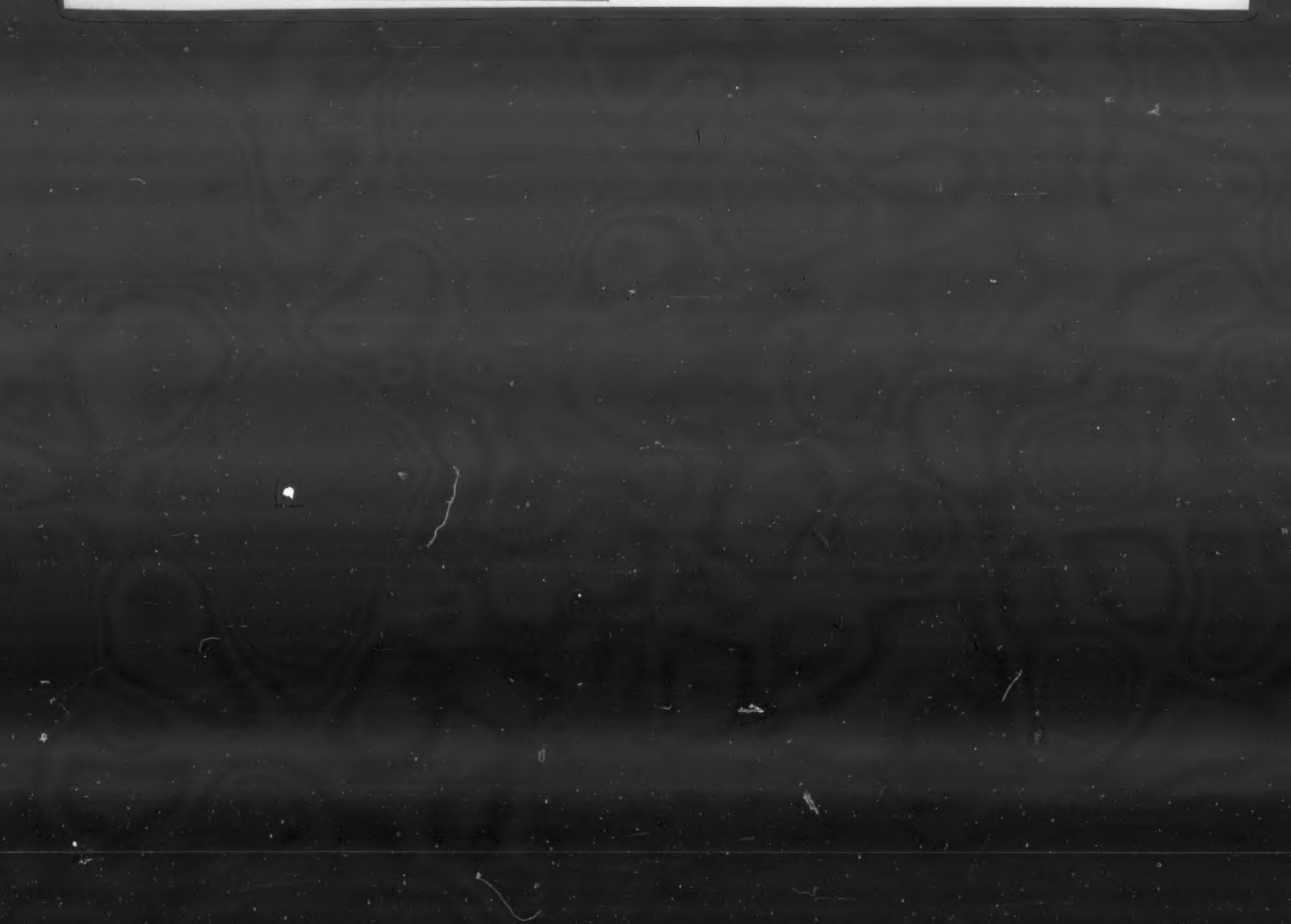
Young later (1807) modified this identification of the characteristic undulations of the three kinds of vibrating particles in the retina with the undulations of red, yellow, and blue light, following a description of the spectrum given by Wollaston. He substituted green and violet for yellow and blue (figure 3).

Some years before Young's first pronouncement, no less a person than John Dalton (1766–1844), having noticed that his appreciation of colours differed from that of his friends, published a careful account of his deviating colour perceptions in the *Transactions of the Manchester Literary and Philosophical Society* (1794). Dalton belonged to the important class of colour-defectives—now known as protanopes—whose defect manifests itself in three main ways: confusion of red and green, possibility of matching white with a spectral colour (wavelength about 496 mμ), and shortening of the red, i.e. a diminished luminosity of the red end of the spectrum. Young mentioned Dalton's paper in the bibliography of his *Natural Philosophy* (1807), and pointed out that Dalton's observations could be explained by the 'absence or paralysis of those fibres of the retina which are calculated to perceive red.' Again, in a few lines, Young had originated a hypothesis which was to exert an influence on colour theory continuing up to the present time. On Young's view it might be expected that there would be two other kinds of colour defect, corresponding respectively to the failure of the green and of the violet processes. In 1837 a study of colour-defectives by A. Seebeck showed that, in addition to those whose colour vision resembled Dalton's, there were others (now known as deuteranopes) who like the first confused red and green but did not show shortening of the red. On Young's theory, deuteranopia would be explained by the failure of the green mechanism.

Facts about colour vision of quite a different kind from those considered hitherto were pointed out by the Czech physiologist J. E. Purkinje (or Purkyně) (1787–1869). In a notable series of observations he established that coloured objects lose their colour when viewed in weak light, that under such weak light blue objects become relatively brighter than red or orange objects, and that small coloured objects when feebly illuminated and looked at directly are visible, if at all, only with difficulty, but become plainly visible as colourless objects on averting the gaze. In his first account, published in Latin in 1823 (*Commentatio de examine physiologico organi visus et systematis cutanei*, Bratislava), Purkinje stated that, in weak light, pigment colours appear in shades of grey and brown. His later conclusions (1825) were based on observations of the changing appearance of coloured objects as dawn broke. The significance of these three important properties of vision could not be fully appreciated until the duplicity theory of vision had been developed.

Recorded observations showing that the colour of an object may be altered if there are other coloured objects near it go back at least to Jurin (1783). We owe to Michel Chevreul (1786–1889), however, the most extensive early account of these phenomena of simultaneous contrast. Chevreul's book *De la loi du contraste simultané des couleurs* dealt not only with the basic phenomena but with the





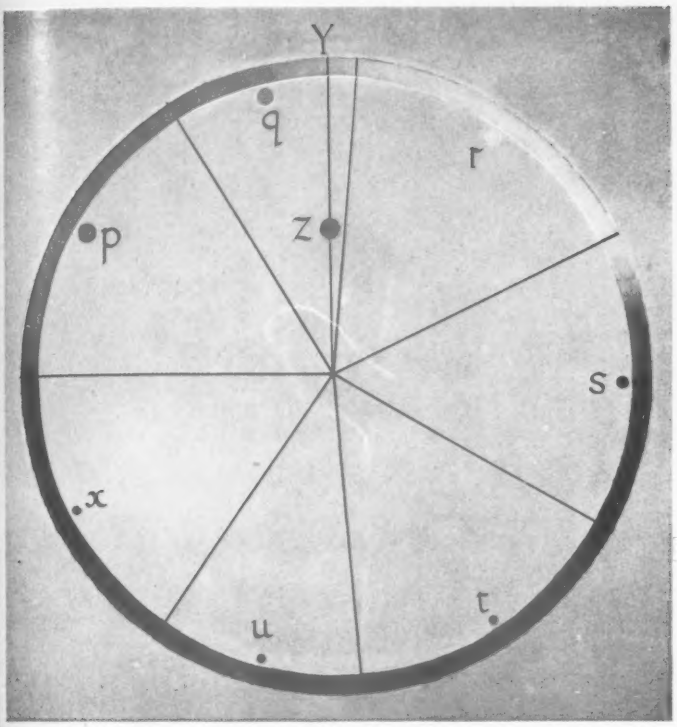


FIGURE 1 – *Newton's colour circle: a reproduction in colour of the line diagram given in Newton's* Opticks (1704).

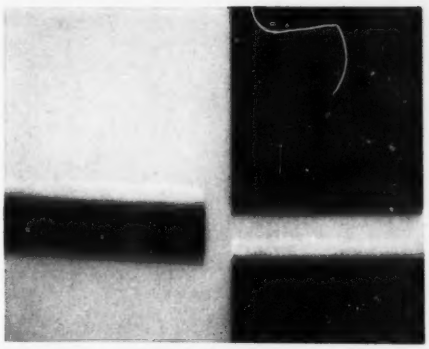


FIGURE 2 – *Goethe's boundary colours, obtained by viewing light and dark strips through a dispersing prism.*

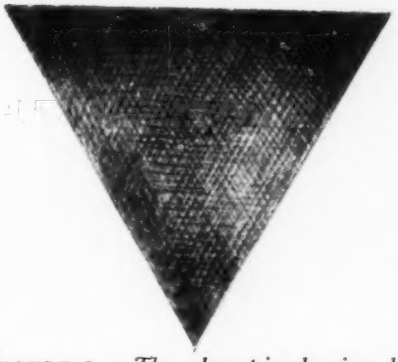


FIGURE 3 – *The colour triangle given by Young as an illustration in his* Natural Philosophy (1807).

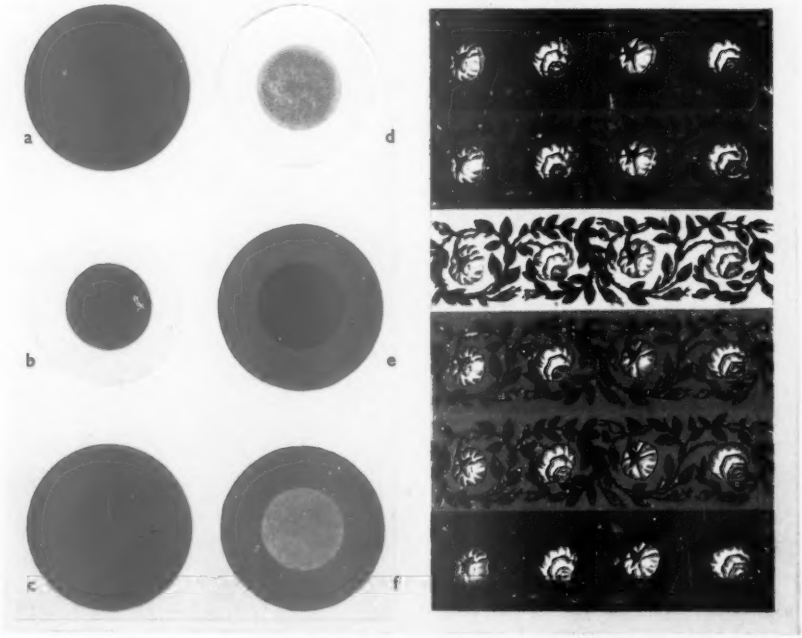


FIGURE 4 – *Plates from Chevreul's book, showing the modifying action of coloured surrounds on a central colour. In the left-hand figure,* a *should be compared with* b, c *with* e, *and* d *with* f.

FIGURE 5 – *Illustrating Grassmann's first law: Blue + red = magenta; green + red = a different colour, yellow.*

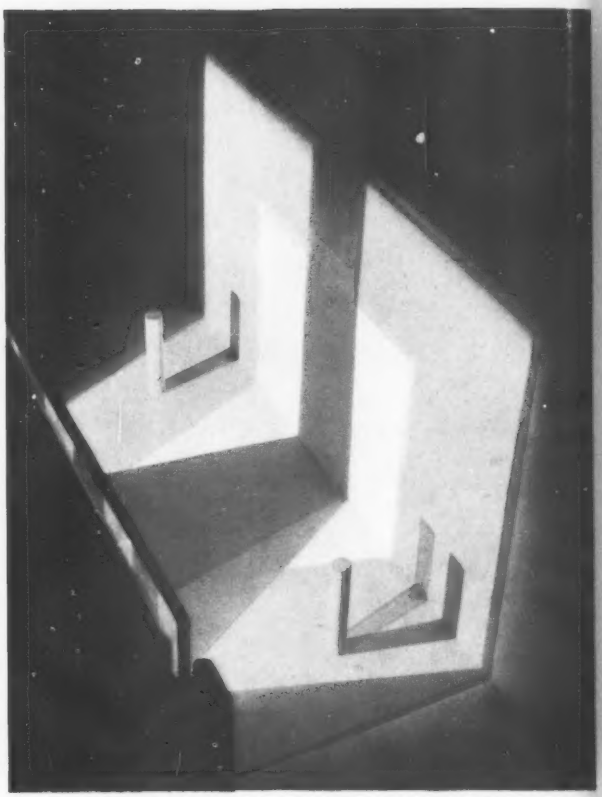


FIGURE 6 – *Illustrating Grassmann's second law: Left-hand, yellow (simple) + blue = white; right-hand, yellow (mixed) + blue = white.*

FIGURE 9 – *One of the two instruments—now known as anomaloscopes—used by Rayleigh when he discovered anomalous trichromatism.*

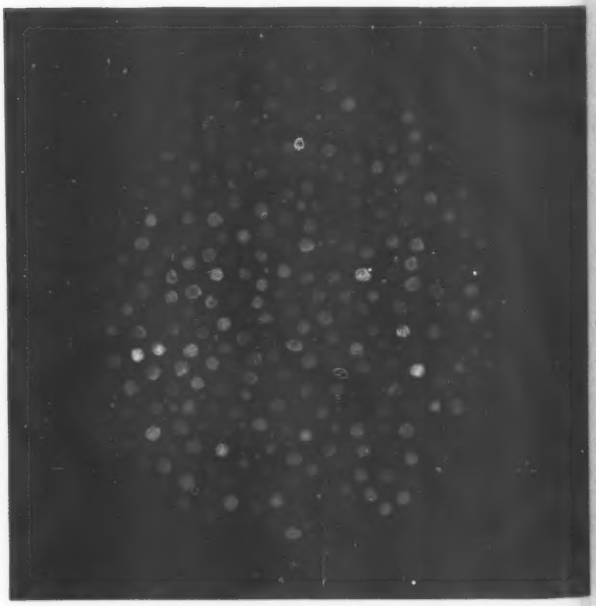


FIGURE 10 – *Colour pattern demonstrating foveal tritanopia. If viewed at about 5 metres the image falls within the fovea and the figure '2' cannot be seen.*

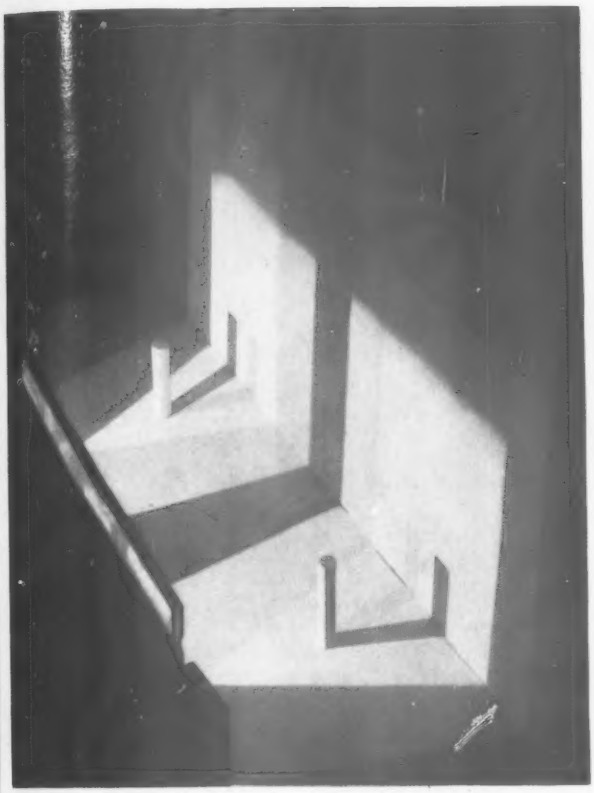


FIGURE 7 – *Illustrating Grassmann's third law: the magenta and orange beams together give a colour which can be matched by mixing white with a spectral colour (in this case red).*

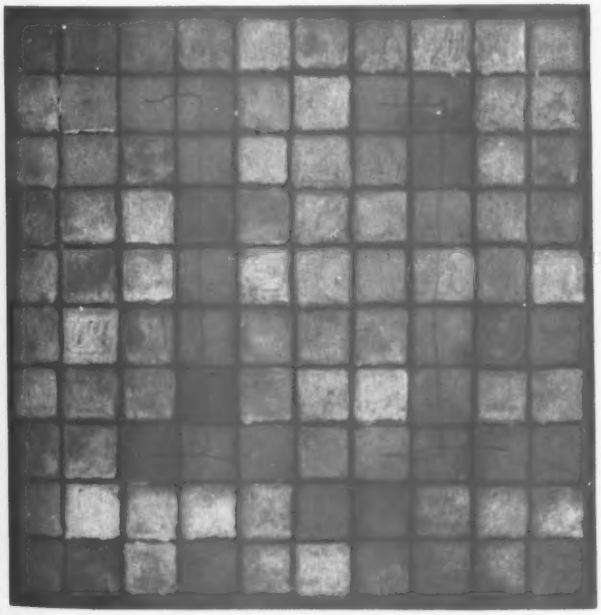


FIGURE 11 – *Colour pattern demonstrating foveal tritanopia. At about 5 metres the figure '11' comes into view.*

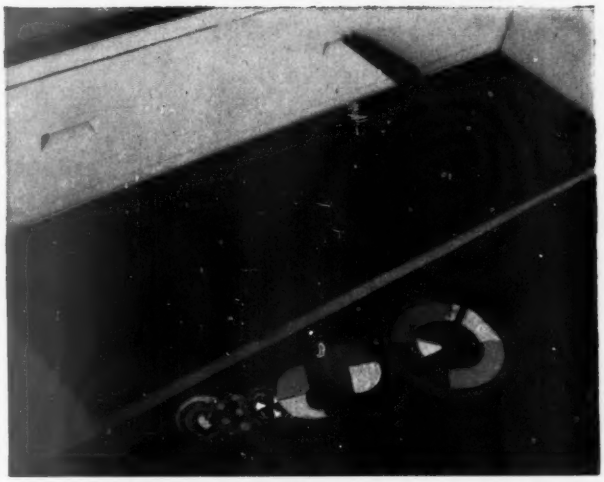


FIGURE 8 – *Maxwell's portable colour box apparatus with additional slit systems. In the foreground, Maxwell's colour top.*

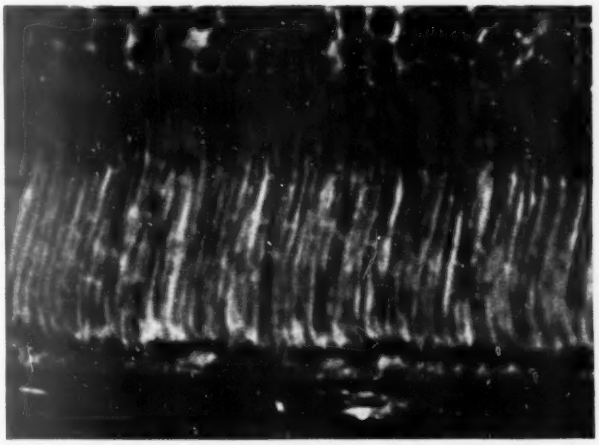


FIGURE 12 – *Section of the retina of a rat's eye, showing rods only.*

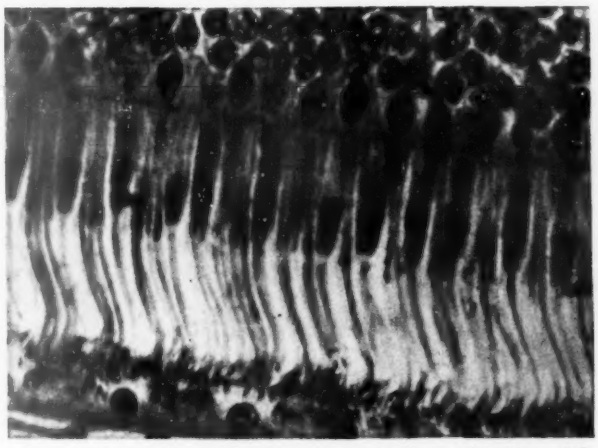


FIGURE 13 – *Section of the retina of a monkey's eye, showing mainly rods but some cones.*

FIGURE 14 – *Munsell colour samples mounted in their correct spatial arrangement.*

FIGURE 15 – *Model showing the colours corresponding to different points in the C.I.E. colour chart. (Model constructed by the Tintometer Company from Lovibond coloured glasses.)*

art of arranging colours in harmonious patterns. As director of the Gobelins tapestry factory he was vitally concerned with the laws of simultaneous contrast. The principles established were, and remain, largely qualitative. Perhaps the most important is that every coloured object tends to modify the colours of neighbouring objects in the direction of its own complementary colour, i.e. the colour which by additive mixture with the original colour would produce white (figure 4).

Neither Newton's rule for determining the resultant of mixtures of colours, nor Young's trichromatic theory, was fully elaborated by its originator, and up to the middle of the nineteenth century their implications had still to be demonstrated and the crucial measurements to test them had still to be made. The attack on both problems was initiated in 1852 by Hermann von Helmholtz (1821–94); his careful determination of the wavelengths of complementary spectral colours appeared in the following year. Meanwhile, stimulated by the work of Helmholtz, the mathematician H. Grassmann (1809–77)—not himself an experimentalist—formulated a set of laws of colour-mixing based largely on Newton's observations. Succinctly stated, Grassmann's laws are as follows: (i) unlike lights mixed with like lights produce unlike mixtures; (ii) like lights mixed with like lights produce like mixtures; (iii) every mixture of lights can be matched by a definite spectral light or purple mixture, mixed in either case with a definite amount of white light (figures 5, 6, and 7).

Helmholtz and Grassmann were closely followed by James Clerk Maxwell (1831–79). In his early work on colour-matching Maxwell used a colour top, and in his hands this simple instrument yielded quantitative results of surprising reliability. Maxwell's greatest contribution, however, was made when he turned to the mixture of spectral lights: the famous colour box was the apparatus he used (figures 8 and 16). He made a great number of matches of various sets of three spectrum colours with white, and by the adroit use of colour equations—a concept warranted by the validity of Grassmann's laws—he determined for the first time the quantities of three fixed primary spectral colours (630·8, 528·6, and 457·4 mμ) which, when mixed, matched the other spectral colours (these quantities plotted against the wavelength of the variable spectral colour represent the so-called mixture curves of the spectrum). This could be done for some spectrum colours only if one

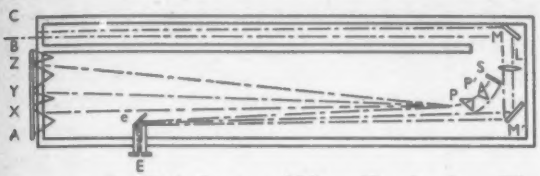


FIGURE 16 – *Optical system of Maxwell's colour box. The three entrance slits* (X, Y, Z) *are illuminated by placing a white board, receiving the sun's light, beyond the end* ABC *of the instrument. These slits supply the three spectral components of the mixture. The intensities are varied by changing the slit widths. The comparison field—always white—is formed of rays entering between* C *and* B. *It is seen abutting on the mixture field at the edge of the prism* P.

admitted the notion of a negative contribution of one of the fixed primaries to the mixture. The negative contribution was to be regarded as mixed with the spectral colour being matched, instead of with the other two primaries. Maxwell was fully aware that, while confirming the central idea of Young's theory, his results did not identify the characteristic undulations of the retina, as the choice of a set of three fixed lights to serve as primaries was to a large extent arbitrary. However, he also studied colour-defectives and showed not only that their colour vision was two-dimensional instead of three-dimensional, but that it was simply related to normal colour vision in a way consistent with Young's explanation of Dalton's defect; adopting this explanation, one at least of the characteristic undulations could be found.

Before 1866, no structures had been observed in human or animal retinae which could be related to the triple process implied by Young's theory, nor had the study of the minute anatomy of the retina provided any hint of the explanation of Purkinje's observations on colour vision. A major advance in this direction was made by the anatomist M. Schultze (1825–74). He showed that the sensitive layer of the retina in which the light rays initiated the visual process (the position of this layer had been deduced by Müller from observations of the shadows cast by retinal blood vessels) was made up of two types of cell differing in shape: rod cells, each equipped with a cylindrical rod-like extension, and cone cells with conical extensions (figures 12 and 13). From observations on numerous vertebrates, some nocturnal, some diurnal, and some active by both day and night, Schultze concluded (i) that vision must be possible with rods alone or cones alone; (ii) that the rods are concerned with vision in dim light (night vision), and the cones with day vision; and (iii) that as the human retina contains both rods and cones (except at the fovea, or small central area) and as colour vision fails in dim light, the rods must be incapable of colour discrimination and the cones must be the cells serving the mechanism of colour vision. This conclusion is strengthened by the superiority of colour vision at the fovea, which contains only cones. Schultze's conclusions are now generally accepted, and form the crux of the duplicity theory of vision.

There is a resemblance between Goethe's hostility to Newton's ideas on colour and the opposition of E. Hering and his followers to the trichromatic theory as elaborated by Helmholtz. In formulating his own theory—the opponent colours theory—Hering placed weight on the fact that only red and green, yellow and blue, give the impression of being simple colour sensations, and that colour contrast effects suggest their pairing in the way indicated. He added the further pair white and black, and postulated for each of these pairs a visual substance which might be present in excess to give one of the associated sensations, or in defect to give the other. The Hering-Helmholtz controversy was prolonged, but is now dead. Hering's views embody a triplicity which, when expressed quantitatively, makes the

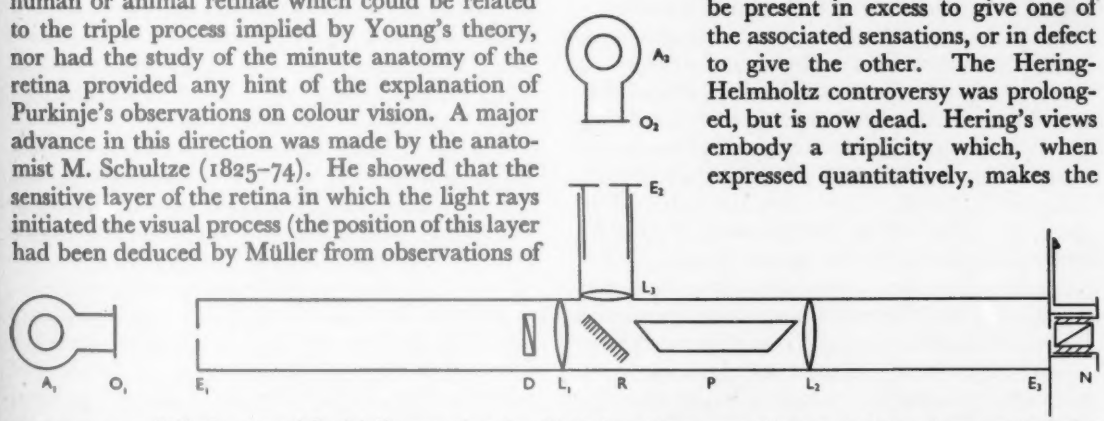


FIGURE 17 – *Optical system of Rayleigh's anomaloscope. Light from the entrance slit* E_1 *is split into beams, polarized at right angles and slightly inclined one to the other, by the double-refracting prism* D. *After collimation by lens* L_1 *the two beams are dispersed by the direct vision prism* P, *and two slightly displaced spectra are focused on the exit slit* E_3 *by the lens* L_2. *Thus the exit slit selects two different spectral bands (red and green) from the two beams, and their relative intensities are varied by turning the nicol* N. *The other half of the visual field is provided by the entrance slit* E_2. *The mirror* R *is adjusted so that the yellow in the spectrum of this beam emerges through the exit slit* E_3. *The entrance slits are illuminated by opal plates* O_1 *and* O_2 *in front of Argand gas flames* (A_1, A_2). *The observer keeps the brightnesses of the halves of the field the same by adjusting the gas tap of the burner* A_2, *which is within his reach.*

theory virtually a form of trichromatic theory. On the other hand, it is now generally conceded that subjective impressions of colour cannot be accounted for without extensions of the trichromatic theory; these have not yet been satisfactorily worked out.

A remarkable new form of colour defect was discovered in 1881 by John William Strutt, the third Lord Rayleigh. While the protanope and deuteranope, lacking one of the three processes of normal trichromatic vision, can match any two spectrum colours in the range from red to green, merely by adjusting the intensity of one of them, the colour-defectives studied by Rayleigh were unable to do this (figures 9 and 17). Like the normal trichromat, they required one particular mixture of red and green in order to match yellow, but the necessary proportions of these colours differed widely from the normal. Some required more red, others more green, so that two new classes of colour-defective—now known as anomalous trichromats of the protanomalous and deuteranomalous types respectively—were defined. Their colour vision is certainly mediated by three processes, but the spectral sensitivities of these processes must be different from those of the normal trichromat.

The surprising observation was made by A. König (1856–1901) in the year 1894 that in the normal trichromatic eye a small retinal area in the centre of the fovea is in fact dichromatic; any stimulus imaged in this area can be matched by a mixture of only two fixed stimuli (spectrum colours of wavelength 475 and 650 mμ in König's experiments, figures 10 and 11). This dichromatism, however, was unlike the previously known forms protanopia and deuteranopia; with it was associated a reduced visibility of weak stimuli from the blue end of the spectrum. A little later (1897), König investigated several persons whose colour-defect arose from disease. From his observations it appears that in these cases the colour-defect could be explained by the failure of the third or violet process of the trichromatic theory. With the discovery of this form of colour-defect—now called tritanopia—three forms of dichromatism, as would be expected from Young's theory, were known. Moreover, as König pointed out, there was a close similarity between the colour vision of tritanopes and that of the normal trichromat in the central fovea.

Helmholtz doubted the feasibility of isolating subjectively the brightness of a coloured stimulus. He believed that another quality—colour glow—would vitiate the measurements. However, König, W. de W. Abney, and others found that so-called heterochromatic brightness-matching was possible, and that curves showing the relative brightness of spectral colours of equal energy could be determined; the latter are called spectral luminosity curves. These workers were, of course, concerned with the relative brightness at moderate or high intensities, at which the colours of the stimuli were clearly seen: at intensities low enough to stimulate only the rod mechanism the colours are not seen and there is no difficulty in making brightness matches. Heterochromatic brightness-matching was much studied because of the important problem of assessing the value of different illuminants. Another practical problem which has stimulated visual research is the display of the whole range of possible colours—or, to be more precise, of possible coloured surfaces—in an atlas or rational arrangement. The most successful attempt (1905) is that of A. H. Munsell, whose colour samples are classified by subjective appraisal according to hue, chroma (apparent saturation), and value (apparent brightness), and are chosen so that as far as possible adjoining samples differ by equal steps of these quantities (figure 14).

The pioneer determinations of the mixture curves of the spectrum and of the spectral luminosity curve (Maxwell, König, Abney) left something to be desired both in the apparatus used and in the number of observers studied. Careful redeterminations have since been made (Wright, Guild, Hyde, Forsythe and Eady, Coblentz and Emerson, Gibson and Tyndall), and, based on these, standard curves were adopted in 1931 by the *Commission Internationale de l'Eclairage* (C.I.E.) to represent the properties of an average eye (figure 15). The C.I.E. also laid down a particular set of reference primaries to be used in specifying colours by the trichromatic method. In a certain sense, the C.I.E. system represents the culmination of the more academic studies of colour vision by Newton, Helmholtz, and Maxwell, while at the same time it is a technological tool of great value.

This article is illustrated with photographs of some exhibits shown by the Physical Society's Colour Group at the Society's 1951 exhibition of scientific instruments. For permission to reproduce these photographs the writer is indebted to Sir Lawrence Bragg (figures 8 and 9), Mr T. R. Bullett (figure 1), Mr G. J. Chamberlin (figure 15), the Colour Group (figure 14), the Goethean Science Foundation (figure 2), Mr R. W. G. Hunt (figures 5, 6, and 7), Dr K. Tansley (figures 12 and 13), and Dr E. N. Willmer (figures 10 and 11).

Experimental breeding of dairy cattle for hot climates

J. P. MAULE

There are two basic methods of breeding for improvement in the productivity of indigenous or local cattle stocks. There is, firstly, selection from the best available strains or types, without the introduction of any other breed. This is, in certain circumstances, the soundest long-range policy. The second method is by crossbreeding, which has tended to show more spectacular and rapid progress in the first few years, though it has a number of disadvantages.

In recent years increased attention has been paid to the problem of developing dairy cattle adapted to hot climates and able to give an economic yield of milk. This has become all the more important because of the need to raise the output of milk and butterfat for human consumption.

The problem is being tackled in two ways, either by the improvement of indigenous cattle—namely of zebu type—or by crossbreeding, mainly between zebu and European breeds.

Crossbreeding of cattle is purely a means to an end, and there are various alternatives for proceeding after the half-bred (F_1) generation. These include grading-up to one or other of the parent breeds, or mating alternately to sires of each breed—the so called criss-cross breeding. The development of new breeds or types of livestock is a direct outcome of crossbreeding combined with selection from within the crossbred types. In so far as zebu (*Bos indicus*) cattle are concerned, crossbreeding has two separate objectives. In the first place, attempts have been made to improve either beef or milking qualities of inferior native or indigenous zebu stock by crossing them with European breeds (*Bos taurus*). The results, in most cases, have not been successful; although the half-bred dairy cow, probably as a result of heterosis, certainly gives more milk than its indigenous dam, there is a rapid loss of constitution and lack of adaptation as the proportion of European blood increases. The alternative system of crossbreeding is designed to improve European stock by infusing into them the characteristic qualities of zebu cattle, such as hardiness, adaptability to hot climates, and ability to make full use of inferior foodstuffs. Work on the crossbreeding of cattle in the tropics for increased milk production has been carried out mainly in India, the West Indies, the Philippine Islands, and East Africa [9]. This includes the use of improved zebu breeds (e.g. the Sahiwal, or Montgomery of India) for crossing with European stock, and it is with this aspect that we are particularly concerned. The fact must not be overlooked, however, that some of the best zebu breeds, developed by careful selection for their milking or beef qualities, are being used to an increasing extent for upgrading or crossing with other, often less well developed, zebu types. Such work is in progress in Africa and South America, and in the East. This development will also be referred to below. Crossbreeding for beef production is outside the scope of this review, but the creation at the King Ranch, Texas, over a period of 25–30 years, of the Santa Gertrudis breed, which was recognized as such in 1940, served to focus attention on the possibilities of combining, in a new breed, the qualities of both zebu and European cattle. Kelley [1] has summarized the extent to which crossbreeding has been carried on in the tropics and subtropics, and has described the ecological considerations involved and the specialization of zebu cattle for tropical conditions.

ADAPTATION OF ZEBU CATTLE

It is as well to mention briefly the qualities in zebu cattle which make them so much better suited to hot climates than European stock.

1. Zebu cattle have a higher tolerance for heat than European breeds.
2. They are tolerant of, or resistant to, many tropical diseases to which European cattle readily succumb.
3. They are credited with a greater efficiency of food utilization and lower food requirements for the production of milk, meat, or work than European breeds. There is, however, little definite proof of this contention.

The most important quality is that of the zebu's high tolerance for heat. By this is meant the animal's ability to balance the gain and loss of heat at a body temperature which is compatible with the proper functioning of the physiological processes. Heat tolerance depends on a number of factors, of which the most important are ability to avoid excessive heat absorption, low heat production by the animal, and ability to get rid of surplus heat fast enough.

Findlay [2] has recently reviewed this whole problem, and further work on the reactions of different types of European cattle is in progress. Bonsma [3], working in South Africa, has drawn attention to the importance of the type of coat and thickness of skin in different breeds. He has also shown that a black skin, and a smooth silky coat with white, yellow, or red hair colour, are the ideal combination to give high heat tolerance.

BREEDING FOR MILK

There is still considerable conflict of opinion regarding the possibility of creating a tropical dairy breed combining the high yield of the European parent with the hardiness, heat tolerance, and adaptability of the zebu parent. The introduction of European cattle into most parts of the tropics, especially where the ultimate aim is the general raising of the level of milk production, is now generally ruled out as being unsatisfactory. Thus Wright [4], describing work done in Ceylon, states: 'It cannot therefore be too strongly emphasized that European cattle suffer from certain grave disabilities in a tropical environment which render them quite unsuitable for milk production except in very limited areas, and under very specialized conditions of management,' and he concludes by saying: 'The detrimental effect of the present methods of uncontrolled crossbreeding (i.e. in Ceylon) is, indeed, apparent from even the most casual survey of the island's existing stock. It is true that such stock do meantime provide a fair proportion of the urban milk supplies, but only at a heavy cost in loss of size, conformation, and constitution, and in a short milking life.'

Much of the pioneer work on crossbreeding, as well as on the selection of indigenous zebu milch breeds, was carried out in India, where crossbreeding on the military dairy farms was designed to increase the production of milk, and little or no account was taken of draft qualities. Though crossbred cattle on the military dairy farms certainly gave higher yields of milk than did ordinary zebu cattle, this work was not of permanent value and did nothing towards the general improvement of Indian dairy cattle.

The recently published results of work carried out at Alabang stock farm in the Philippines between 1932 and 1940 [11] have tended to confirm the previous reports regarding the unsuitability of high-grade European cattle (in this case, Ayrshires) in the tropics. The yields of $\frac{1}{2}$, $\frac{3}{4}$, and $\frac{7}{8}$ Ayrshire grades, resulting from crosses of Ayrshire bulls with indigenous or Indian cows, fell from 3212 lb in 276 days in the F_1 to 2549 lb in 240 days for the $\frac{3}{4}$ bred, and 1718 lb in 191 days for the $\frac{7}{8}$ grade, with 20 per cent. mortality in the latter and 47 per cent. mortality in the $\frac{15}{16}$ grade. By comparison, Red Sindhi cows (one of the smaller zebu breeds) averaged 2240 lb in 245 days.

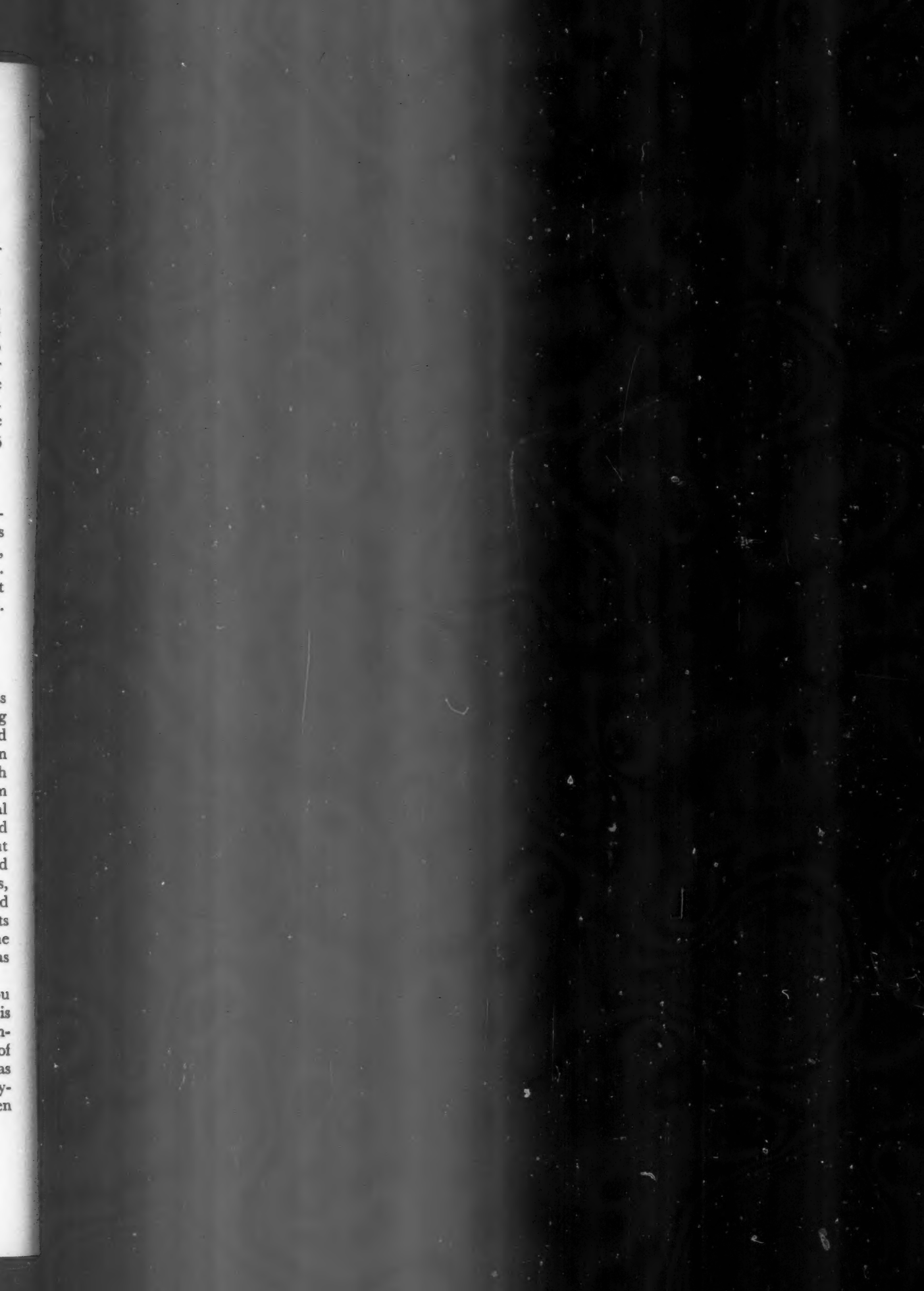
ADAPTATION OF PURE-BRED CATTLE

Before dismissing the possibility of acclimatization of European dairy cattle in the tropics as impracticable, it is worth noting that Shorthorns, Friesians, and Jerseys have done well in Fiji [12]. Moreover, a strain of Jerseys in Jamaica has not shown any deterioration over a period of 38 years. Further reference to this strain is made below.

EXPERIMENTAL BREEDING IN THE WEST INDIES

In the West Indies, work has been in progress for over thirty years with the object of establishing a type of dairy cow combining both European and zebu blood and adapted to local conditions. In Trinidad [8], this work has been mainly with Holstein-Friesians and zebu stock derived from importations of Ongole, Mysore, and Sahiwal cattle from India; in Jamaica, the zebu blood used was largely derived from one Sahiwal bull, but crosses were made with Jersey, Guernsey, and Holstein cattle; while in the Leeward Islands, crosses between Senegal (N'Dama) cattle and Red Polls have been made. The most detailed results have been obtained in Jamaica, where, of the three European dairy breeds tried, the Jersey has proved to be the most satisfactory.

An analysis of the three breeds and their zebu crosses has been made by Howe [5]. This analysis shows that the half-bred Jersey-zebu and Holstein-zebu gave, respectively, the highest percentage of butterfat and highest milk yields. There was little difference between the $\frac{3}{4}$ and $\frac{1}{2}$ Guernsey-zebu. This is shown below, all yields being given in lb for 305-day lactations:



IGURE 1 – *Half-bred* (F_1) *Red Sindhi* × *Tanganyika zebu. Photograph by J. W. T. Holloway.*)

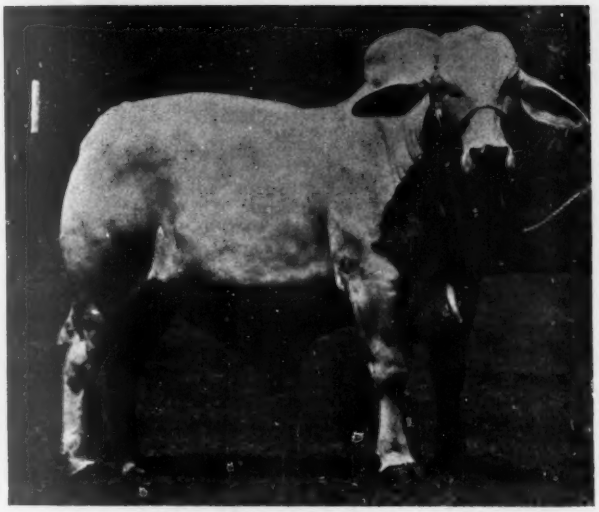


FIGURE 2 – *This steer is* $\frac{7}{8}$ *zebu and* $\frac{1}{8}$ *Jersey, and weighed* 1800 *lb at* 3 *years. There is little evidence of the Jersey blood. He was bred in Florida, U.S.A., and won a grand championship for beef steers.*

FIGURE 3 – *Three-year-old Santa Gertrudis steers on the King Ranch, Texas. These steers averaged* 2610 *lb live weight.*

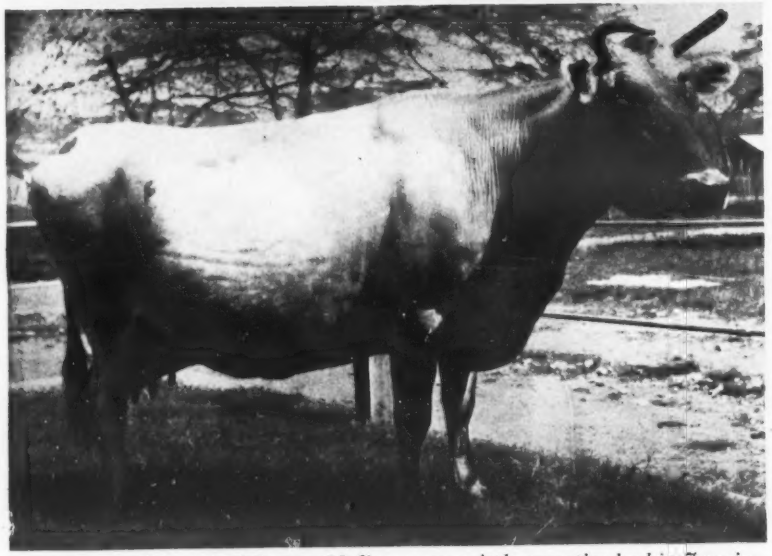


FIGURE 4 – *A pure-bred 8-year-old Jersey cow; sixth generation bred in Jamaica. She is the typical ash-fawn colour of the heat-tolerant strain, weighs 1000 lb, and gave 544 gal milk and 288 lb butterfat in 1949.*

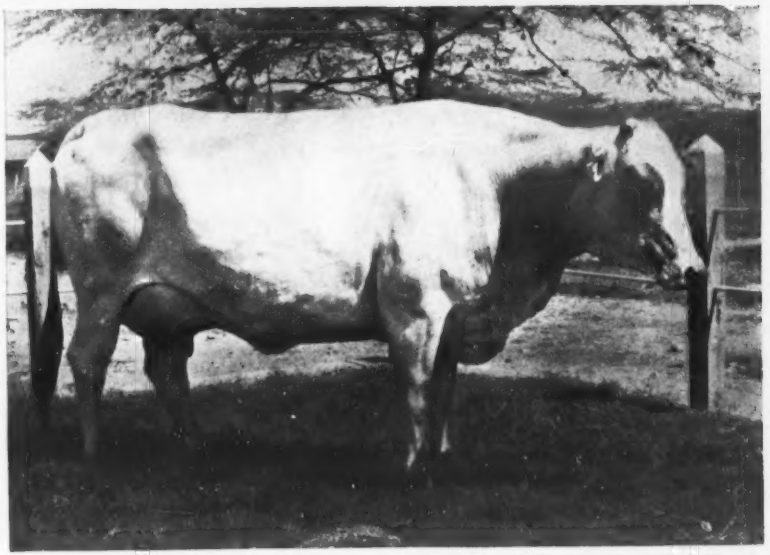


FIGURE 5 – *A grade Sahiwal-Jersey cow in Jamaica. This cow is nearly ¾ Jersey. She gave over 900 gal milk in 1950. In colour this cow is light fawn, tending towards silver.*

FIGURE 6 – *A ¾-bred Holstein-Friesian cow in Trinidad, by a pure-bred Friesian*

FIGURE 7 – *Sindhi bull. This breed is found in both Pakistan and India and is pre-*
eminently a zebu dairy breed

FIGURE 6 – *A ¾-bred Holstein-Friesian cow in Trinidad, by a pure-bred Friesian*

FIGURE 7 – *Sindhi bull. This breed is found in both Pakistan and India and is pre-eminently a zebu dairy breed*

	Pure-bred	¾	½	¼	Av. all crossbreds	
					Milk	Butterfat %
Jersey	4,020	4,156	3,192	4,520	3,997	5·18
Guernsey	3,549	3,304	3,967	3,993	3,881	5·11
Holstein	—	3,740	5,104	5,506	5,142	4·25

More recently, a detailed study of the Jamaican work with Jerseys and Holsteins based on a comparison of different families has been made by Lecky [6]. The Jersey work has revealed two things not brought out in the earlier analysis. Firstly, that two families of pure-bred Jerseys have been bred which are apparently adapted to the local climatic conditions and have given consistently good milk yields. Secondly, that, contrary to Howes' results, grades containing from ¾ to ⅞ Jersey blood gave the best results. Here, too, several families were found to give outstandingly good yields, and one in particular may be developed by inbreeding into a fixed type suitable for the tropics.

In his study, Lecky places emphasis on production of both milk and butterfat rather than on type, and has disregarded the conventional method of fractional breeding. Thus the families of grade Jersey-zebus all contain varying amounts of zebu blood. This zebu blood is mainly (but not entirely) derived from the one pure-bred Sahiwal bull which was imported to Jamaica in 1920. The average yields of these different families are as follows:

Yields of selected Jersey and Jersey-zebu families in Jamaica

Family	Number of Animals	Percentage with more than ¾ Jersey blood	Av. 305-day lactation yield		Max. milk yield lb
			Milk lb	Butterfat lb	
Pure-bred Jersey					
Honeybelle	29	—	5,327	263·6	7,293
Perfection	23	—	5,185	257·6	7,369
Grade Jersey					
Norbrook	20	75	6,474	354·4	11,393
Dolly	11	82	5,118	267·3	7,499
Madge	18	95	4,583	240·2	7,808
Ada	16	94	4,326	223·5	6,937

The Norbrook family is clearly outstanding, and the present intention is to line breed this and the Honeybelle family, and select from them two types of hardy, high-producing dairy cattle. It is interesting to note that three of the best cows in the Norbrook family had no Sahiwal blood, and that the 29 daughters of the Sahiwal bull averaged only 4693 lb milk and 243 lb of butterfat.

In comparing results with Holstein cattle in Jamaica [10] and in Trinidad, where Jerseys have not been imported, it is noteworthy that whereas the ¾ bred is considered to be the best type in Trinidad, the half-bred was found to be superior in Jamaica (see below). However, though there has been no analysis of the Trinidad work comparable with that of the Jamaican, two facts emerge from the available reports. The first is that no strain or type of crossbred Holstein-Friesian has been bred possessing the hardiness and milking ability (especially in terms of butterfat) of the Jerseys and

Milk Yields of Holstein-Friesians in the West Indies

Type	Trinidad Av. lactation yield in lb	Jamaica Av. 305-day yield in lb
Pure-bred	2,979	—
⅞ grades	3,612	3,740
¾ grades	4,486	5,104
½ grades	4,316	5,506
¼ grades	3,287	—

Jersey-zebu grades in Jamaica. Secondly, the pure-bred or high-grade Friesian, both in Trinidad and Jamaica, shows a striking loss of constitution, is slow to mature, and is difficult to get in calf. Thus in Jamaica the percentage of discards among grade Holstein-Friesians was as high as 53, average age at first calving for 61 cows in 1935–48 was 3½ years, and the interval between calves was 18 months, while in Trinidad this interval was, for pure-breds, just over 17 months.

An entirely different approach has been made at the Allahabad Agricultural Institute in India, where an attempt is being made to evolve a type of Jersey × Red Sindhi cross with as little as $\frac{1}{32}$ part of Jersey blood. This experiment aims at improving the known dairy qualities of the Red Sindhi by infusing just sufficient Jersey blood to raise the total yield of milk and butterfat. The pure-bred Red Sindhi had an average yield of 3084 lb milk, and crossed with a Jersey bull the first cross cow gives nearly 50 per cent. more milk (4551 lb), but back-crossing of the Red Sindhi reduces this, and the $\frac{1}{16}$ Jersey gives only 26 per cent. more milk

than the pure-bred Sindhi. Although the two breeds are said to cross very well, and both yield a high butterfat content, it seems problematical whether this type, if eventually fixed, will be greatly superior to the best strains of Red Sindhi in India. Average yields of over 4000 lb have been obtained with Sindhis at Government farms in India.

The value of the Red Sindhi for crossing with the Jersey in other countries where a high degree of heat tolerance is required is likely to be of special interest. Millen [7], when he started the Allahabad experiment, remarked on the fact that this crossbred had a particularly pleasing appearance, and that the two colours blended well. It is all the more interesting, therefore, to know that an experiment in crossing these two breeds is now being undertaken by the U.S. Department of Agriculture at Beltsville, Maryland. This is a long-range experiment begun late in 1946, when two Sindhi bulls and two heifers were imported from Allahabad. The bulls were mated to Jersey cows with the object of comparing the milk production, growth rate, and heat tolerance of these first crosses, and later of the back crosses, with the pure-bred Jerseys. To date, 29 females and 21 males have been born, and the first 10 F_1 heifers have completed their first lactations on thrice daily milking. The average yields of the ten heifers and that of their dams (first lactations) were as follows:

	Milk lb	*Butterfat %*	*Butterfat lb*	*Age at First Calving*
				yr mths yr mths
10 F_1 Sindhi × Jersey daughters	8,697	5·92	515	1 11 to 2 2
9 Jersey dams ..	9,588	5·75	551	1 11 to 3 5

Growth rate has been slightly greater in the crossbred heifers than in either their Jersey dams or the pure-bred Sindhis. The F_1 crosses were less affected by exposure to a hot atmosphere and had a lower respiration rate than the Jerseys.

Although it is too early to assess the value of this experiment, these preliminary observations suggest that the Sindhi × Jersey cross may provide a basis for developing a suitable heat-tolerant dairy cow. The F_1 heifers were mostly red in colour, but the F_2 back-cross to Jersey resembles the Jersey very closely and has no hump at all.

To sum up this work on crossbreeding for milk production in the tropics and subtropics, there are three questions to be answered, namely: (1) What are the most suitable breeds with which to start? (2) To what extent has the development of crossbred types been successful? (3) What are the chances of creating new types of cattle suitable for general upgrading of dairy stock in the countries concerned?

The most suitable European breed seems undoubtedly to be the Jersey. This breed crosses well with the zebu and appears to be more adaptable to hot climates than other breeds. Of the zebu breeds, the Sahiwal and Red Sindhi both seem to be successful, although, of the two, the Sindhi may be preferable.

The second point is that, with the exception of the Jamaican work, very little progress has been made in developing a crossbred tropical dairy cow. However, there is some evidence to suggest that a crossbred Jersey-Sindhi or Jersey-Sahiwal cow may be developed.

The third point is by no means easy to answer at this stage. It does not follow that improved types of dairy cattle raised under the best farm conditions will be successful in the general upgrading of indigenous or unimproved dairy stock. Moreover, it is by no means certain that such a policy would be practicable or desirable in many areas. Thus it may be inferred that new types would at first be confined to special areas and to chosen breeders, and would not be widely distributed for breeding.

REFERENCES

[1] KELLEY, R. B. Zebu-cross cattle in N. Australia, *Coun. Sci. Indust. R. Bull.*, No. 172, 1943.

[2] FINDLAY, J. D. 'The Effects of Temperature, Humidity, Air Movement and Solar Radiation on the Behaviour and Physiology of Cattle and Other Farm Animals.' A review of existing knowledge. *Bull. Hannah Dairy Inst.*, No. 9, 1950.

[3] BONSMA, J. C. *J. agric. Sci.*, **39**, 204, 1949.

[4] WRIGHT, N. C. 'Report on the Development of Cattle Breeding and Milk Production in Ceylon,' *Eastern*, No. 179, 1945.

[5] HOWE, J. W. *Trop. Agric.* (*Trin.*), **26**, 33, 1949.

[6] LECKY, T. P. 'The Hope Jerseys,' *Bull. Dept. Agric.*, No. 42, *Jamaica*, 1949.

[7] MILLEN, T. W. *Indian Fmg.*, **8**, 8, 1947.

[8] HARRISON, E. *Trop. Agric.*, **21**, 3, 1944.

[9] KENYA: DEPARTMENT OF VETERINARY SERVICES. 'Colony and Protectorate of Kenya. Annual Report, 1948. Govt. Printer, Nairobi, 1950.

[10] LECKY, T. P. 'The Hope Holsteins,' *Bull.* No. 44, *Dept. Agric., Jamaica.* 1950.

[11] RIGOR, T. V., and ROBLES, M. M. *Philippine J. Anim. Ind.*, **10**, 389, 1950.

[12] TURBET, C. R. *Agric. J., Fiji*, **20**, No. 3, 1949.

William Higgins, chemist (1763–1825)

T. S. WHEELER

At intervals during the past 150 years, the claims of William Higgins to have anticipated Dalton as the originator of the atomic theory in its nineteenth-century form have frequently been preferred—not always with urbanity. Much of the biographical matter previously published is inaccurate in detail. This account of the life of Higgins is largely based on primary sources hitherto unexamined. The author, in his professorship at Dublin, is ninth in succession to Higgins.

William Higgins was born, probably at Collooney, Co. Sligo, Ireland, in 1762 or 1763. He came of a family of doctors (figure 1), one of whom, his uncle Bryan Higgins, turned to chemistry and set up a laboratory in Greek Street, Soho, London. William studied with his uncle as a youth before proceeding to Oxford, where he matriculated at Magdalen Hall on 6th February, 1786 [1]. Later, he migrated to Pembroke College, where his name first appears on the buttery books on 16th March, 1787. While at Oxford, he worked in a laboratory in the basement of the Old Ashmolean Museum, which now houses the Museum of the History of Science. He mentions [2] that the chemical 'elaboratory' in which he worked was nearly six feet below ground, and that a mixed crop of sodium, potassium, and calcium nitrates grew on the walls every three or four months. The manuscript of a paper which he wrote on the analysis of the human calculus dated 'Oxford, April 2, 1787' is in the archives of the Royal Society, as is an account of his reading it to the Society on 3rd April, 1788. The Society did not print the paper, and Higgins included it as an appendix to his *Comparative View* [3]. It was probably at Oxford that Higgins carried out the numerous experiments mentioned in that book.

It is said that William also acted as an operator (presumably lecture assistant) to Thomas Beddoes, the reader in chemistry [4]. From Pembroke College buttery books it appears that Higgins left Oxford in the middle of 1788 without taking a degree. He wrote the *Comparative View* in that year, and published it in March 1789. It sold about 1000 copies, passing through two editions in the course of two years [5]. This work, written when he was about 26, represents his greatest achievement. Its contents will be discussed later in this article.

CHEMIST TO THE APOTHECARIES' HALL, DUBLIN (1792–5)

After William left Oxford, we have no information on his activities beyond a statement by Sullivan [6], his first biographer, that he quarrelled with his uncle Bryan through espousing the cause of the anti-phlogistonists [19]. He reappears in 1791, when a meeting of members of the Apothecaries' Hall, Dublin, held on 1st November, records the receipt in answer to an advertisement of 'two letters from Mr William Higgins in London . . . offering himself to this Corporation as Chemist on certain terms.' He was appointed, and was sworn into office on 13th April, 1792, receiving £200 per annum, apartments, coals, and candles. We are also told that the treasurer was ordered to 'provide furniture for the small back room on the first floor for the use of our Chemist' [7]. The scientist is ever the denizen of the small back room.

Higgins served the directors of the Hall, generally to their satisfaction, for three years, fitting up a laboratory and preparing chemicals and galenicals for their shop. In 1795, however, the Corporation got into financial difficulties, an economy committee reported that the cost of the laboratory greatly exceeded the value of the entire output, and Higgins was informed that there was no further occasion for his services. He seems to have taken the abrupt retrenchment of his post graciously, for the directors recorded their thanks for the masterly manner in which he had fitted up the laboratory, his zeal for the institution, and his offer of advice and assistance. This rare feeling between employer and discharged employee did not last. The Corporation could not pay Higgins the year's salary due to him. However, 'Mr Higgins having importuned this Court collectively and individually for his salary' they resolved that 'for the honour of this Company two hundred pounds be borrowed to pay Mr Higgins.' Although Higgins can hardly be blamed for his importunity, his language—as happened all too frequently in his life—was such as to rankle, and the directors decided that he had behaved 'in a

very unbecoming manner' and used 'very unhandsome language.'

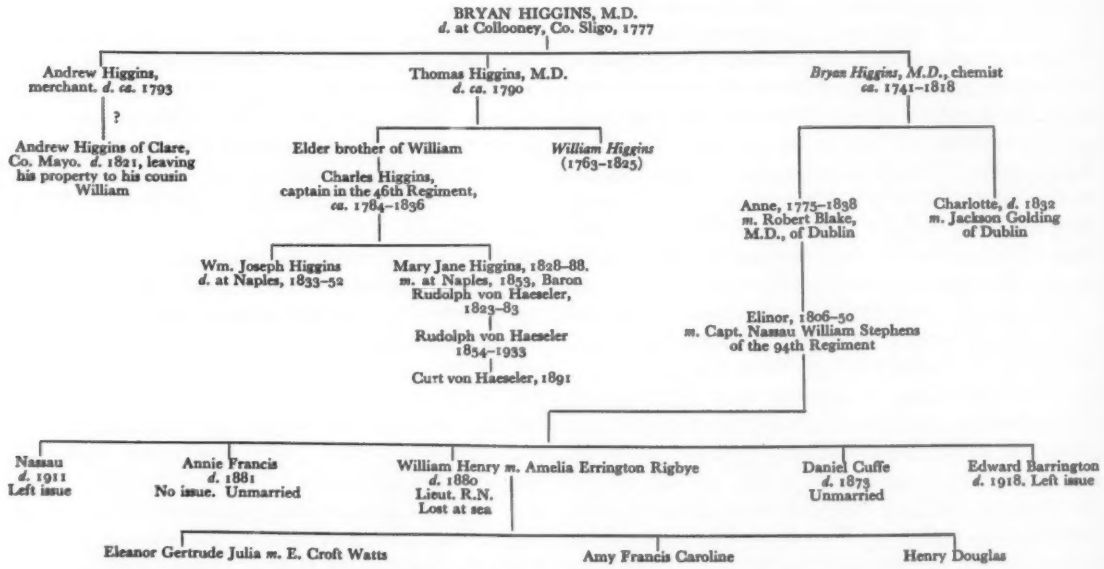
CHEMIST TO THE IRISH LINEN BOARD (1795–1822)

We leave Higgins in the process of departing from the Apothecaries' Hall, and pause to discuss a phase of his career hitherto completely neglected. Early in 1795 he had been appointed part-time 'chymist,' at £100 per annum, to the Irish Linen Board, which had been set up in 1711 to control the linen trade. It was government-nominated and unpaid, so that attendance of trustees was poor, except when there was a post to be filled. The methods of administration were lax, and the commissioners of public accounts were doubtful of the legality of Higgins' appointment; they allowed it only because they regarded him as a professional man or a tradesman and not as an officer of the Board. To their credit it may be mentioned that the Board had sought chemical advice as early as 1716 [8].

This appointment led Higgins to take an interest in the chemistry of bleaching, on which he published an essay in 1799. He claimed that calcium sulphide could replace 'pot-ash,' with considerable economy in the cost of materials. He served the Board as a general consultant until, in 1822, during a government economy drive, the trustees abolished the posts of clerk of works, messenger, watchman, and, of course, 'chymist.' Higgins' protest against the discontinuance of his post, which is entered in the minutes of the Board, contains the pathetic statement that 'Men of science meet with protection in every enlightened nation.' He forgot the country was not at war.

WITH THE ROYAL DUBLIN SOCIETY (1795–1825)

Higgins was eventually paid by the directors of the Apothecaries' Hall up to 20th June, 1795. He was not without a powerful friend, for on 18th June the council of the Dublin (later Royal Dublin) Society agreed to a suggestion of the famous chemist Richard Kirwan to appoint Higgins as supervisor of the Leskean collection of minerals, then recently acquired for about £1300. Kirwan recommended Higgins as skilled in mineralogy, but the Society, who knew quite well that Kirwan's main desire was to befriend a colleague, and that Higgins was a chemist and not a mineralogist, decided in view of 'Mr Higgins's extensive skill in Chymistry' to equip a laboratory for him.


BRYAN HIGGINS, M.D.
d. at Collooney, Co. Sligo, 1777
Andrew Higgins, merchant. d. ca. 1793
Thomas Higgins, M.D. d. ca. 1790
Bryan Higgins, M.D., chemist ca. 1741–1818
?
Andrew Higgins of Clare, Co. Mayo. d. 1821, leaving his property to his cousin William
Elder brother of William
Charles Higgins, captain in the 46th Regiment, ca. 1764–1836
William Higgins (1763–1825)
Anne, 1775–1838 m. Robert Blake, M.D., of Dublin
Charlotte, d. 1832 m. Jackson Golding of Dublin
Wm. Joseph Higgins d. at Naples, 1833–52
Mary Jane Higgins, 1828–88. m. at Naples, 1853, Baron Rudolph von Haeseler, 1823–83
Rudolph von Haeseler 1854–1933
Curt von Haeseler, 1891
Elinor, 1806–50 m. Capt. Nassau William Stephens of the 94th Regiment
Nassau d. 1911 Left issue
Annie Francis d. 1881 No issue. Unmarried
William Henry m. Amelia Errington Rigbye d. 1880 Lieut. R.N. Lost at sea
Daniel Cuffe d. 1873 Unmarried
Edward Barrington d. 1918. Left issue
Eleanor Gertrude Julia m. E. Croft Watts
Amy Francis Caroline
Henry Douglas

This table is based on information supplied by the Irish genealogists Mr Edward Keane, Mr J. C. T. MacDonagh, and Dr R. C. Simington, and material obtained from the Irish Public Record Office and the Registry of Deeds. Information has also been supplied by the Public Record Office and the War Office, London, by Mr Edmund Nicholls, London, and by H.M. Consul-General, Naples. Many too numerous to mention, including various solicitors in Dublin, have also helped. Herr Curt von Haeseler of Weimar, who was traced by a letter to the *Stadtverwaltungsdirektor* of Weimar, has been most courteous in answering queries. Legal documents in Dublin had shown that Mary Jane Higgins had become Baroness von Haeseler of Weimar.

FIGURE 1 – *Abbreviated genealogy of the Higgins family.*

The Society did not accept Kirwan's recommendation that Higgins should also look after the library. About 1796, Higgins became professor of chemistry and mineralogy by an act of the Irish parliament, and by 1800 his salary was as much as £300 per annum; he also had a share in lecture fees. He had no lodging from the Society, who in 1796 shelved a motion to provide apartments for him [9].

Higgins did not take long to organize lectures in chemistry. An advertisement for a lecture course appeared in a Dublin newspaper for 31st January, 1797. Through all the years in which he served the Society, he gave more attention to lecturing than to any other activity. He did little about the mineralogical side of his post, and in 1812 the Society decided to appoint a separate professor of mineralogy.

Higgins' manner brought him into conflict with the Society on a number of occasions. There are references in the minutes to improper behaviour towards members with whom he had disagreed, and there are statements given in evidence in 1836 before a committee of the House of Commons on the Society, that he was a difficult man. In March 1825, Higgins was reported to the Society as absent through indisposition; he made his will on 28th April, and on 30th June the Society received news of his death. There is no record of it in the contemporary Dublin papers. Although a professor of chemistry, he died a wealthy man. In 1821 he inherited property in Co. Mayo from his cousin Andrew (see figure 1), and in 1823 he purchased land in Queen's County (now Co. Leix) for £6800. He left his property to his nephew Captain Charles Higgins, and £100 each to his cousins Anne Blake and Charlotte Golding, daughters of Bryan Higgins. He does not appear to have married.

His publications were few. Apart from the *Comparative View* (1789) [2] and the *Essay on Bleaching* (1799), his only other book was *Experiments and Observations on the Atomic Theory and Electrical Phenomena* [5], published in 1814 to support his claim to be the originator of the atomic theory as applied to chemical phenomena. A paper on the use of calcium sulphide and two on meteorites also appeared under his name. Finally, there are five polemical papers on the origins of the atomic theory in the *Philosophical Magazine* between 1816 and 1819.

He was elected to the Royal Irish Academy in 1794 and to the Royal Society in 1806. His certificate of election was signed by, among others, Humphry Davy and Richard Lovell Edgeworth, father of the Irish novelist Maria Edgeworth and father-in-law of Thomas Beddoes. He did not sign the obligation in the charter book and obtain admittance to the Society until 1st May, 1817; hitherto it has been assumed that he did not sign the book.

HIGGINS AND THE ATOMIC THEORY

We now seek to assess Higgins' status in regard to the useful application of the atomic theory to chemical phenomena. It is difficult to make the required evaluation of merit. Since 1814, many people—fifty at least—have written to dispute the subject, yet the controversy between Daltonians and Higginsians flares up at intervals and dies down still unextinguished [18]. The *Comparative View* is not an easy book to read, and, even when Higgins' ideas have been grasped, it is necessary to consider them against the background opinion of the time.

There is one aspect of his achievement which immediately strikes the reader of his book. Higgins was the first to use the initial letters of the names of elements as symbols for their atoms, and to write molecular structures showing these letters linked by bonds (see figure 2). He employed, for example, S for sulphur (p. 39, *c.v.*) [10]; d or D for dephlogisticated air [oxygen] (p. 39); P for phlogisticated air [nitrogen] (p. 133, figure 2); I for iron (p. 48) and for inflammable air [hydrogen] (p. 45); C for copper (p. 262). The importance of a system of symbolism of this type should not be underestimated: it enabled Higgins to discuss reaction-mechanisms in inorganic chemistry in a simple and economical manner—he seems (p. 193) to have an idea of transition compounds—and must have facilitated his thinking about atoms and their interactions to form molecules. He was interested in the forces between the atoms in a molecule, and attempted to express them by numbers. His speculations in this respect have no modern importance and need not be further discussed.

HYDROGEN AND OXYGEN

We now consider Higgins' views on the composition of water (p. 37). This compound can be formed, or—as far as Higgins knew—decomposed, in one stage only. Hence assuming, as Dalton did, a rule of greatest simplicity, 'we may justly conclude, that water is composed of molicules [*sic*] formed by the union of a single particle of dephlogisticated air to an ultimate particle of light

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inflammable air, and that they are incapable of uniting to a third particle of either of their constituent principles.' Water is therefore HO or, as Higgins wrote it (p. 45), I—D. Further, as two volumes of hydrogen react with one volume of oxygen, hydrogen contains half as many particles per volume as oxygen: we have here a hint of Gay-Lussac and Avogadro.

Again, for Higgins the specific gravity of hydrogen was 2·613 and of oxygen 34 (p. xiv; the figures are taken from Kirwan's values for the absolute weights in grains of 100 cu in of different kinds of air), so that for him an atom of oxygen would be $34/(2 \times 2{\cdot}613)$, that is 6·5 times as heavy as an atom of hydrogen. He does not state this explicitly in the *Comparative View*, though he remarks (pp. 2, 148) that the proportion by weight of oxygen to hydrogen in water is 6 or 7 to 1. He made the point definitely later [11].

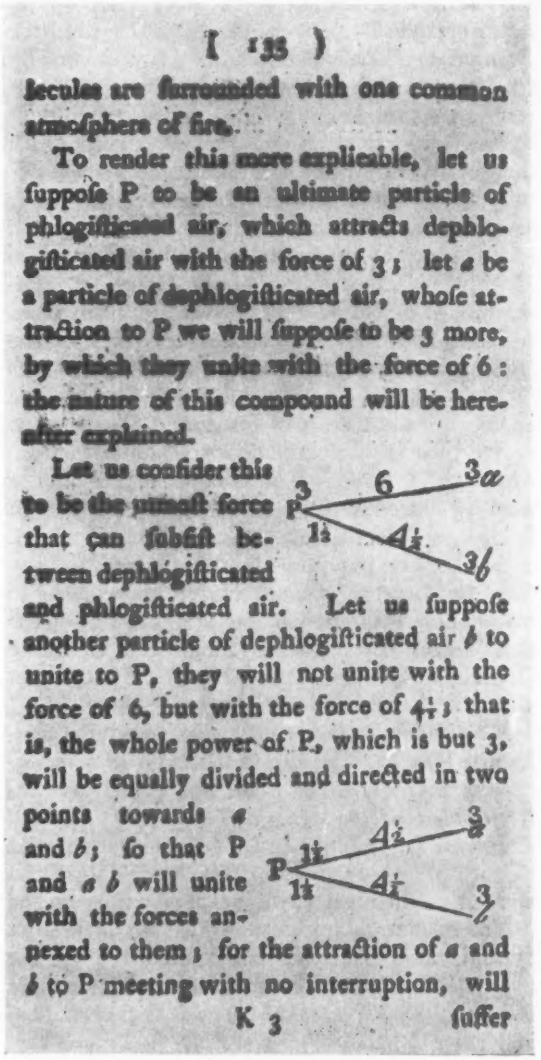
SULPHUR AND OXYGEN

Higgins' argument (p. 36) in regard to sulphur dioxide may be paraphrased thus: sulphur dioxide contains equal weights of sulphur and oxygen: therefore its molecules contain equal weights of these elements. Further, if we assume (rule of greatest simplicity) that sulphur dioxide is SO (Higgins wrote S—d; p. 43), the atoms of these elements must be equal in weight. The specific gravity of sulphur dioxide is approximately twice that of oxygen, so that sulphur dioxide contains its own volume of oxygen, in agreement with experiment. It follows also that the number of molecules and particles respectively in equal volumes of sulphur dioxide and oxygen will be the same (p. 81). Higgins also stated that sulphuric acid, exclusive of water, contains twice as much oxygen per unit weight of sulphur as sulphur dioxide (p. 37), so that it is $S\overset{d}{\diagup}D$ (p. 40).

It will be noted that Higgins regarded the equality in particle weight of sulphur and oxygen as something to be proved, but as with Dalton his rule of simplicity led him astray.

NITROGEN AND OXYGEN

Higgins' statements (see figure 2) regarding the compositions of the oxygen compounds of nitrogen, which he wrote as NO to NO_5 (pp. 133–5, 171), have often been quoted, for they show a visualization of the law of multiple proportions. He is not altogether clear as to how he arrived at his views, but he gives gravimetric and volumetric results which guided him (pp. 82 *f.*, 132 *f.*, 164 *f.*). We quote in illustration (p. 132): 'In my opinion, the purest nitrous [nitric] acid [N_2O_5; the composition of acids was not understood] contains 5 of dephlogisticated to 1 of phlogisticated air. Nitrous air [nitric oxide], according to Kirwan, contains 2 of dephlogisticated to 1 of phlogisticated air. According to Lavoisier, 100 gr of nitrous air contain 32 gr of phlogisticated air, and 68 of dephlogisticated air. I am myself of the former philosopher's opinion: I likewise am of opinion, that every primary particle of phlogisticated air is united to two of dephlogisticated air, and that


[135]

lecules are furrounded with one common atmoſphere of fire.

To render this more explicable, let us ſuppoſe P to be an ultimate particle of phlogiſticated air, which attracts dephlogiſticated air with the force of 3; let *a* be a particle of dephlogiſticated air, whoſe attraction to P we will ſuppoſe to be 3 more, by which they unite with the force of 6: the nature of this compound will be hereafter explained.

Let us conſider this to be the ſmalleſt force that can ſubſiſt between dephlogiſticated and phlogiſticated air. Let us ſuppoſe another particle of dephlogiſticated air *b* to unite to P, they will not unite with the force of 6, but with the force of 4½; that is, the whole power of P, which is but 3, will be equally divided and directed in two points towards *a* and *b*; ſo that P and *a b* will unite with the forces annexed to them; for the attraction of *a* and *b* to P meeting with no interruption, will

K 3 ſuffer

FIGURE 2 – *From the* Comparative View. *This page illustrates Higgins' use of symbols to represent atoms and his views on the relative forces between them.*

these molecules are surrounded with one common atmosphere of fire' [12].

In his *Atomic Theory* (pp. 117 and 119), Higgins makes it clear that, in the ratios quoted above, he intended composition by volume. On the other hand, in the *Comparative View* (p. 83) he suggests, though not clearly, that weight ratios were involved. Possibly the crude experimental results available to Higgins would not show much difference between weight and volume ratios for oxygen and nitrogen. He believed (p. 14) that equal volumes of nitrogen and oxygen contained under the same conditions equal numbers of ultimate particles, from which follow the structures he gives for NO and N_2O_3. Later (*Atomic Theory*, pp. 144, 146), when he knew the correct volume composition of nitric oxide, he modified his views, and wrote 'In my opinion, the ultimate particles of azote are larger and of course heavier than those of oxygen. I also conceive that a measure of oxygen gas contains twice the number of ultimate particles that are contained in the same volume of azotic gas.'

HYDROGEN SULPHIDE

Higgins tended to the view that hydrogen sulphide consisted of sulphur suspended in its natural state in hydrogen, i.e. that it was a solution of sulphur in hydrogen (pp. 13, 72, 73, 77, 80). He deduced the particle ratio in which the two elements were present in hydrogen sulphide from the results obtained by exploding hydrogen sulphide with an equal volume of oxygen (p. 80). He knew that hydrogen sulphide contained its own volume of hydrogen, and he observed that when allowance had been made for the volume of oxygen condensed to water by the hydrogen—free, as he thought, in the hydrogen sulphide—the residual oxygen gave its own volume of sulphur dioxide. The specific gravity of the latter gas is approximately twice that of oxygen and of hydrogen sulphide, when a deduction is made for the hydrogen present. Hence, per unit volume, the number of molecules of sulphur dioxide is equal to the number of particles in oxygen and to the number of sulphur particles in hydrogen sulphide. But the particle number, per unit volume, of hydrogen is half that of oxygen, so that 'the numbers of the ultimate particles of sulphur in hepatic gas [hydrogen sulphide], are to those of inflammable air as' two to one. He wrote by mistake 'nine to five' in the *Comparative View* (p. 81), but he corrected the figure to 18 to 9 in his *Atomic Theory* (p. 84). Actually he did not need the explosion experiment to get his result, as he knew the composition of sulphur dioxide (see section on SULPHUR and OXYGEN, above) [13].

DALTON AND HIGGINS

Nash [14] summarizes Dalton's contributions to the atomic theory as follows:

(1) He gave a plausible, precise, and unambiguous statement of the basic postulates of his theory; (2) he made atomic weights the keystone of his theory—possibly by chance; '. . . this stress was rapidly fruitful of a new usefulness for, and a new faith in, the atomic theory'; (3) he employed the 'rule of greatest simplicity,' which was an invaluable contribution to the development of the atomic theory; '. . . the rule represented a bold and intelligent choice of a simplifying assumption'; (4) his symbolism for the representation of atoms and their combinations was an important development.

It is considered that the quotations from the *Comparative View* given above indicate that Higgins anticipated Dalton in regard to Nash's points (3) and (4). In regard to point (1) Higgins is at fault, for he gave no clear statement of his views. His contemporaries certainly did not read a new theory into his book; perhaps he was before his time. He was mainly concerned with the refutation of the current phlogiston theory, and his basic interest was not in a novel atomic theory; at any rate he wrote nothing on the subject until 1814, some seven years after Dalton's ideas had reached the scientific world. It is greatly to be regretted that he did not follow up the *Comparative View* by further work on the subject; had he done so the polemical literature of chemistry might be less by one in unresolvable subjects for discussion. We can never know whether or not Dalton read the *Comparative View* when developing his theory.

Nash's point (2) covers the strong point of Dalton's theory and the weak point of Higgins'. It is not accurate to state, as some, including the present writer [15], have done, that Higgins assumed all atomic weights to be the same. He thought it necessary to prove equivalence of atomic weight for oxygen and sulphur, and it is possible, though there is no definite proof, that he made an obvious deduction and realized that the weight of his hydrogen particle was one-seventh of that of the oxygen particle [11]. Yet nowhere does he emphasize the importance of atomic weights. He was, of course, restricted by the chemical knowledge of his time to volumetric work with simple gases.

Undoubtedly, as stressed by Partington [16], William thought atomically because he had worked with his uncle Bryan, who applied Newton's ideas on atoms to the explanation of chemical phenomena. Bryan had clear ideas on atoms and molecules, but the development of his theory was hampered by the fact that he thought there were seven elements: earth, water, acid, alkali, air, phlogiston, and light; his discussions were qualitative and his ideas rudimentary. It seems to the present writer possible to sustain the thesis that William was the first to approach an atomic symbolism of the modern type [17] and to apply a Daltonian species of theory to the determination of the molecular composition of some common gases; he was the first, too, to use the law of greatest simplicity, to have an inkling of Avogadro's law, and to suggest the law of multiple proportions. If these statements are accepted, and so far there has been no general agreement on their validity [18], Higgins would appear to have some claim to be considered the originator of the chemical atomic theory. It was Dalton, nevertheless, who formulated the theory so that it became generally acceptable to chemists. Perhaps justice would be done to both men if the theory were called the Higgins-Dalton theory. But it is probably too late—as with Newlands and Mendelejeff—to put back the hands of the clock.

The author is greatly indebted to many correspondents and librarians, who have helped him in compiling material for a detailed biography of William Higgins, which he hopes eventually to publish. He would like especially to express his gratitude to Professor J. R. Partington, a Daltonian, with whom he has had many friendly arguments, and from whom he has learned much concerning the state of chemistry in the time of William Higgins. His thanks are also due to Mrs J. Conan for assistance in assembling material.

NOTES AND REFERENCES

[1] The author is indebted to Mr Lionel E. Salt, Fellow and formerly Bursar of Pembroke College, for much new information on Higgins' stay at Oxford. The approximate year of Higgins' birth is fixed by an entry in J. Foster's *Alumni Oxonienses*.

[2] *A Comparative View of the Phlogistic and Antiphlogistic Theories. With Inductions. To which is annexed an Analysis of the Human Calculus, with Observations on its Origin, etc.* By William Higgins, of Pembroke College, Oxford. Murray, London. 1789 and 1791; p. 176.

[3] See note [2] for full title.

[4] Bryan Higgins (*Nicholson's Journal*, **1**, 130, 1802) says William was operator to the professor of chemistry. Hitherto this has been taken to be Thomas Beddoes (1760–1808), who was actually reader in chemistry, but the matter requires further investigation. In the same reference Bryan calls William his 'cousin,' which raises an uneasy doubt as to whether the traditional uncle-nephew relationship is correct. Figure 1 is believed, however, to be substantially accurate.

[5] See *Phil. Mag.*, **53**, 405, 1819; also *Experiments and Observations on the Atomic Theory and Electrical Phenomena.* By William Higgins, Esq., F.R.S. and M.R.I.A., Professor of Chemistry to the Dublin Society. Longman, Hurst, Rees, Orme, and Brown, London. 1814; p. 10. Messrs Longmans have kindly supplied a photograph of their ledger account with Higgins. They are still owed £3 2s.

[6] SULLIVAN, W. K. *Dublin Quart. J. of Med. Sci.*, **8**, 465–95, 1849.

[7] The author is greatly indebted to the late Dr J. T. Daniel, Registrar of the Apothecaries' Hall, Dublin, who made freely available for the first time the minute book of that corporation.

[8] The details of Higgins' connection with the Linen Board are taken from the minutes of the Board.

[9] This account of Higgins' connection with the Royal Dublin Society is taken from the minutes by courtesy of the Registrar (Dr H. H. Poole) and the Librarian (Mr D. J. Clarke).

[10] *Comparative View.* Where a page number only is given this book is intended.

[11] *Phil. Mag.*, **53**, 408, 1819. It must be admitted that we here assume Higgins made an obvious deduction from his results; it was not until after the publication of Dalton's views he stated that he had done so. In assessing Higgins' claims it is necessary to confine consideration to what he published in 1789.

[12] William adopted an idea of his uncle Bryan that gaseous particles are surrounded by an atmosphere of fire or heat which prevents them from condensing. Dalton also adopted this view. See J. R. Partington, *Annals of Science*, **4**, 278, 1939.

[13] Higgins' work is summarized by Dr Frederick Soddy, F.R.S., a Higginsian, in *The Story of Atomic Energy*. London. 1949.

[14] NASH, L. K. *The Atomic-Molecular Theory*. Harvard University Press, 1950; p. 27.

[15] *Studies* (Dublin), **39**, 6, 1950.

[16] *Annals of Science*, **4**, 274, 1939. This article gives an account of the development of the atomic theory from the earliest times.

[17] This was pointed out by J. Reilly and D. T. MacSweeney, *Proc. Roy. Dublin Soc.*, **19**, 139, 1929.

[18] See *Nature*, **167**, 120, 734, 1951.

[19] *Added in proof.* The author has recently found in the library of the British Museum (Mss. No. 38392/*f*/104) a Minute of the Privy Council, dated 10th May, 1790, which mentions an application from Ambrose Godfrey, Chymist, and William Higgins of Pembroke College, Oxford, requesting a reward for a new method of printing linens. There is an account, by R. B. Pilcher, of the Godfrey family in *Ambix*, **2**, 17, 1938.

Book reviews

HARMFUL INSECTS

Insects and Hygiene, *by J. R. Busvine. Pp. xiv + 482. Methuen and Company Limited, London.* 1951. 30*s. net.*

There is a heterogeneous collection of insects and other Arthropods liable from time to time to provide problems for the housewife, the sanitary inspector, and the medical officer of health. They comprise the insects that infest foodstuffs or destroy timber, furniture, or textiles; the blood-sucking lice, fleas, bugs, and mosquitos; the houseflies and other flies breeding in garbage—a collection which defies any attempt at logical classification. It is with all such diverse pests that this book deals. They are treated not only from the anatomical, physiological, and ecological points of view but from the legal standpoint and, of course, from the standpoint of control. It is a feature of the book that the general principles of insect morphology, physiology, and ecology, and the principles that should guide the use of insecticides, are outlined before specific problems are considered and practical recommendations made. In some sense, therefore, this is an elementary textbook of entomology, besides being a practical handbook on the insects affecting hygiene in Great Britain. The book is well illustrated, and maintains throughout an admirable balance in the treatment of the various topics.

V. B. WIGGLESWORTH

ANTIBIOTICS

Handbook of Antibiotics, *by A. L. Baron. Pp.* 303. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1951. 52*s. net.*

This book, at first sight expensive, contains a large amount of accurate information in readily accessible form, and provides excellent value for all those who are interested in antibiotics.

The greater part is devoted to a highly condensed summary of factual information, culled from the literature dealing with some 141 named antibiotics (exclusive of synonyms, for which cross-references are given) arranged alphabetically. The references are self-contained for each substance, and are therefore easily consulted. The information, as far as it is available, is cast into the following general form. After mention of the origin or discovery of the antibiotic, its production is dealt with under the headings fermentation, isolation, and purification. A section on chemistry follows, which is subdivided into constitution, properties, reactions, and synthesis. The bacteriology is then presented, under the headings assay, unit of activity, inhibitory concentration to various organisms *in vitro*, factors affecting activity, development of resistance, potency against and range of organisms inhibited *in vivo*, and mode of action. A section on pharmacology and a miscellaneous paragraph conclude the summary. Few errors have been detected: the potency of laterosporin as quoted appears 100 times too high, owing to the substitution of 'γ/ml' for 'units/ml'; the potency of gladiolic acid (p. 128) suffers similar errors; gliotoxin (p. 130) is said to be 'readily oxidized with sulfur.'

Apart from introduction, indexes of authors, of organisms, and of antibiotic-producing organisms, and a six-page glossary, there are a brief chapter by Henry Welch on certification of antibiotics, and two chapters by Walter J. Derenberg on the registration and selection of trade marks for antibiotics, with a list of the present registrations. Since it is a handbook the work is uncritical, and so covers a somewhat different field from the monographs on one or more antibiotics which have already appeared.

N. G. HEATLEY

GROWTH OF CRYSTALS

Crystal Growth, *by H. E. Buckley. Pp. xii + 571, with 168 line diagrams and 88 plates. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 72*s. net.*

This book does not claim to instruct the specialist in his own speciality, but aims to deal with many aspects, theoretical and practical, at a level suited to the general reader who has an interest in some branch of the subject. After an introduction on solution, solubility, and so-called supersolubility there is a description of various methods of preparing crystals. These include the ways of making very large single crystals and other specimens required in research and industry. Theories of crystal growth, particularly those of Stranski and Kossel, are discussed. An account of the nature of imperfections in crystals makes little reference to X-ray evidence; it is followed by sections on dissolution phenomena, modification of crystal habit by impurities, parallel growths and similar effects, and the peculiarities of crystal growth arising from the chemical and physical condition of the crystal environment.

The book contains a great deal of useful information and is provided with numerous illustrations and an extensive bibliography.

In some places the author quotes original papers and in others adapts, although not always happily. For example, Borgström would not enjoy the mathematics attributed to him. One section, a guide to a paper by Stranski, describes at some length the contents of columns one to four of a short table which is not reproduced. There is much parenthetic comment, and even bracket within bracket. It would perhaps be unfair to quote anacolutha, but there are examples of incoherence which would not have survived a second reading.

H. M. POWELL

AETHER AND ELECTRICITY

History of the Theories of Aether and Electricity: The Classical Theories, *by Sir Edmund Whittaker. Pp. xiv + 434. Thomas Nelson and Sons Limited, London.* 1951. 32*s.* 6*d. net.*

The first edition of this great work was published in 1910, and the book has long been out of print. It provided an historical account of theories of the aether and of electricity and magnetism from the times of Bacon and Descartes up to the early years of the present century. At that time rapid developments were taking place, on the theoretical as well as on the experimental side. It is sufficient to mention the Michelson-Morley experiment, J. J. Thomson's work on the conduction of electricity in gases, the discovery of X-rays and of the Zeeman effect, and the investigations of Larmor and Lorentz. Since the publication of the first edition the subject has been revolutionized by the development, for instance, of the special and general theories of relativity, the quantum theory, and wave mechanics; the work of Rutherford, of Niels Bohr, and of their followers in atomic physics; the discovery of cosmic rays and of new fundamental particles. Sir Edmund felt that a new edition must include an account of these new developments; the heavy task of preparing a fully documented account had to be deferred until retirement from his professorial

chair provided him with sufficient leisure.

The volume under review is the revision of the original work and deals only with the classical theories. It is to be followed by a second volume, which will continue the story to the present time. The book has been to a large extent rewritten, and much new matter has been added. It now begins with the science of the ancient Greeks, and an entire new chapter has been inserted on classical radiation theory, which prepares the way for the quantum theory.

The book is fascinating to read and is in addition a valuable work of reference, with detailed notes about original sources. Sir Edmund Whittaker is to be congratulated on carrying through so heavy and important a task with such conspicuous success.

H. SPENCER JONES

RECENT VIEWS ON EVOLUTION

Animal Evolution: a Study of Recent Views of its Causes, *by G. S. Carter. Pp.* 368 + *xii. Sidgwick and Jackson Limited, London.* 1951. 30*s. net.*

It is strange that, though academic biological teaching has been based on evolutionary doctrine for ninety years, evolution itself has occupied only a minor part in the curriculum. With the rediscovery of Mendel's work in 1900, it has been possible to analyse the processes of evolution. During the last ten years or so, there has been much detailed examination of the manner of working of natural selection, based largely on the work of R. A. Fisher and H. J. Muller. Nevertheless this is the first general textbook on the subject.

It is divided into two parts. The first deals with the basis of biological fact concerning evolution, the second with the present state of the theory of evolution. The first includes a clear and attractive account of the genetic background. The discussion of the species problem is perhaps less satisfactory. It introduces to the student the useful term deme for the organization of the members of a species into communal populations. This Dr Carter regards as a general and fundamental fact of natural history. He gives attention to the relation of demes to species and to other 'infraspecific categories.' There necessarily comes under consideration the direct evidence for active selection in natural populations. Very interesting is the case of the moth *Boarmia repandata*. This moth is normally a lightish brown, but darker forms have long been known to be common in the country round London. In the Yorkshire mining areas, sooty and even almost black specimens are found. The species is protected by its colouring, as are all those that exhibit melanic variation in industrial districts. The melanic variety of *B. repandata* is a genetic dominant with a higher viability than the lighter form. Nevertheless, in non-industrialized country, the melanic form being less cryptic, the selection balance turns against it, despite higher viability. This is direct evidence of the effectiveness of selection in nature.

Part II describes the various types and degrees of evolution: micro-evolution within a single population, observable in living animals, and the large evolutionary changes in geological time, somewhat clumsily distinguished as macro-evolution and mega-evolution. Discussion of these introduces the great problems of pre-adaptation, and rates and trends of evolution. The numerous technical terms here necessary suggest the only serious criticism of an excellent book. The reader's path would be smoothed by the provision of a glossary. This would both aid the student and involve a greater closeness in definition and use of terms. CHARLES SINGER

PHYSICAL CHEMISTRY

The Structure of Physical Chemistry, *by C. N. Hinshelwood. Pp. viii* + 476. *Oxford University Press, London.* 1951. 35*s. net.*

Sir Cyril Hinshelwood has put all chemists—indeed, virtually all scientists—immensely in his debt by looking back from the present peak of physical chemistry and telling us, from his own profound knowledge of the subject, of the salient features in the long climb that lies behind, and their relationship to each other.

The book surveys the whole field of physical chemistry under six main headings: simple molecular theory; quantum theory; the electrical basis of matter; forces; matter in equilibrium; and matter tending towards equilibrium. It is an outstanding work, and one whose value will endure whatever new discoveries may be made. It is a model of English prose, a very lucid and interesting exposition of a complicated subject which, in less skilled hands, can—and often does—seem frankly dull.

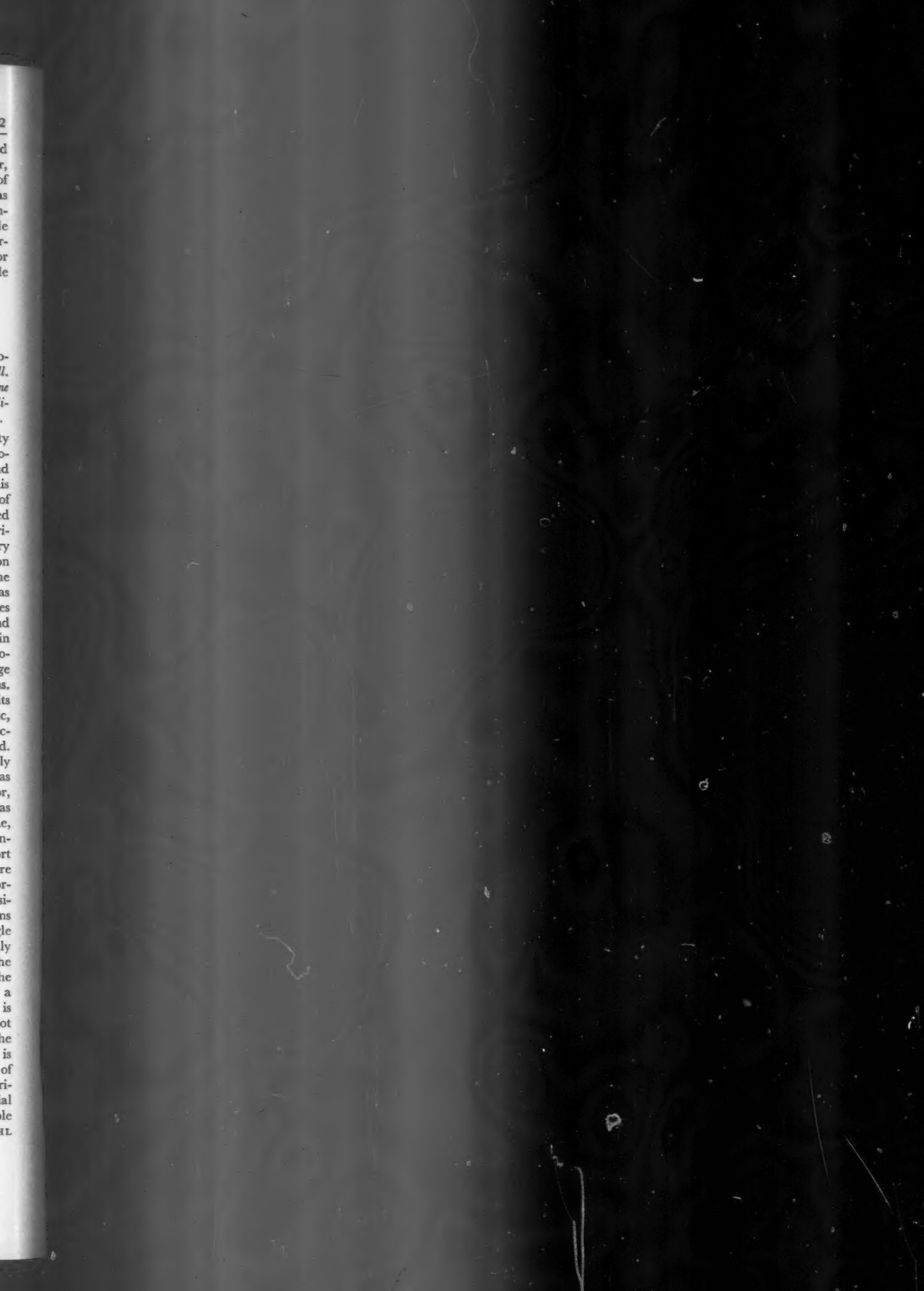
The student, hard pressed by the present high cost of books, may be tempted to ignore the claims of this work on his pocket, as it is not in any sense a textbook; he will be ill advised to yield to the temptation, however, since for acquiring an understanding of physical chemistry as a whole, as opposed merely to learning the unadorned facts, no work of comparable value is available. The Oxford University Press is to be congratulated for keeping the price at a very reasonable figure for a book of this size.

PHOTOGRAPHIC SENSITIVITY

Fundamental Mechanisms of Photographic Sensitivity, *by J. W. Mitchell. Pp.* 347, *with numerous line and half-tone illustrations. Butterworth's Scientific Publications Limited, London.* 1951. 63*s. net.*

This book contains roughly fifty lectures given at the Bristol photographic congress of March 1950, and a good summary by the editor. This summary was written after the close of the congress. In it, Mitchell has tried with much success to fit the new experimental results into a consistent theory of the photographic process based on the ideas of Mott and Gurney. The lectures are divided into five groups, as at the congress: 1, physical properties of silver halides; 2, production and properties of silver halide grains in photographic emulsions; 3, photographic sensitivity; 4, latent image formation; 5, nuclear track emulsions.

At a physical meeting, even when its purpose is to handle a specialized topic, there is always a danger that the lectures will cover only a part of the field. The resulting report will then give only a very incomplete survey of the field as a whole. It is to the credit of the editor, who as secretary of the meeting was largely responsible for the programme, that this danger has been almost entirely avoided. Of course, the report does not resemble a textbook, where each subject receives space in accordance with its importance. The sensitization of photographic emulsions with organic dyes is treated in a single lecture; chemical development is only just touched upon. In contrast, the new plates for nuclear research are the subject of fifteen lectures, almost a quarter of the book. This, however, is no disadvantage. The book is not intended as an introduction; on the contrary, it will give the reader who is acquainted with this field a good idea of the present problems and newer experimental results. It should be of special interest to all those who were not able to attend the congress. R. W. POHL



Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

BIOCHEMISTRY

The Vitamin B Complex, *by F. A. Robinson. Pp.* 668. *Chapman and Hall Limited, London.* 1951. 60*s. net.*

BIOLOGY

Cold Spring Harbor Symposia on Quantitative Biology. *Volume XV, Origin and Evolution of Man. Pp. xii* + 425. *The Biological Laboratory, Cold Spring Harbor, New York.* 1950. $7 *net.*

L'Évolution Biologique, *by Lucien Cuénot, with the collaboration of Andrée Tétry. Pp.* 592, *with* 197 *figures. Masson et Cie., Paris.* 1951. 2500 *fr. net.*

BOTANY

Botanica, *by G. Gola, G. Negri, and C. Carpelletti. Pp.* 1199, *with numerous half-tone and line illustrations. Unione Tipografico Editrice Torinese, Turin.* 1951. 10,600 *lire net.*

CHEMISTRY

Autoren-Namen als chemische Begriffe. Ein alphabetisches Nachschlagebuch, *by Kurt G. Wagner. Pp.* 264. *Verlag Chemie, Weinheim/Bergstr.* 1951. *DM.* 14.80 *net.*

A Short Guide to Chemical Literature, *by G. Malcolm Dyson. Pp.* 144. *Longmans Green and Co. Limited, London.* 1951. 8*s.* 6*d.* net.

Chemical Engineering Science. *Editor: M. B. Donald. Six issues per volume of approximately* 300 *pages. Pergamon Press Limited, London.* 1951. £4 10*s. net per volume.*

Chemical Indicators, *by O. Tomíček. Pp.* 258, *with many line diagrams. Butterworth's Scientific Publications, London.* 1951. 21*s. net.*

Encyclopaedia of Chemical Reactions, *Volume IV, compiled and edited by C. A. Jacobson. Pp.* 790. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1951. 112*s.* net.

Fluorine and its Compounds, *by R. N. Haszeldine and A. G. Sharpe. Pp.* 153. *Methuen and Co. Limited, London.* 1951. 8*s.* 6*d. net.*

An Introduction to the Chemistry of Silicones, *by Eugene G. Rochow.* (2*nd edition.*) *Pp.* 213. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 40*s. net.*

Mellor's Modern Inorganic Chemistry. *Revised edition by G. D. Parkes. Pp.* 967, *with several line diagrams. Longmans Green and Co. Limited, London.* 1951. 25*s. net.*

Organic Reactions, *Volume VI. Editor-in-chief, Roger Adams. Pp.* 517. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 64*s. net.*

Preparation of Organic Intermediates, *by David A. Shirley. Pp.* 328. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 48*s. net.*

The Surface Chemistry of Solids, *by S. J. Gregg. Pp.* 297, *with various line diagrams. Chapman and Hall Limited, London.* 1951. 30*s. net.*

ENGINEERING

An Introduction to the Theory of Control in Mechanical Engineering, *by R. H. Macmillan. Pp.* 195, *with numerous line drawings. Cambridge University Press, London.* 1951. 30*s. net.*

Mathematical Engineering Analysis, *by Rufus Oldenburger. Pp.* 426, *with several line and half-tone diagrams. Macmillan and Co. Limited, London.* 1951. 45*s. net.*

GENERAL SCIENCE

The Neglect of Science, *by F. E. Simon. Pp.* 138. *Basil Blackwell, Oxford.* 1951. 8*s.* 6*d. net.*

GEOLOGY

Marine Geology, *by P. H. Kuenan. Pp. viii* + 568, *with several line diagrams and maps. Chapman and Hall Limited, London.* 1951. 60*s. net.*

Principles of Geology, *by James Gilluly, Aaron C. Waters, and A. O. Woodford. Pp.* 640, *with* 306 *half-tone and line illustrations. W. H. Freeman and Co., San Francisco, Calif.* 1951. £2 8*s.* 10*d. net.*

Palaeographical Atlas, *by Leonard J. Wills. Pp.* 64, *with* 22 *plates. Blackie and Son Limited, London.* 1951. 21*s. net.*

Stratigraphy and Sedimentation, *by W. C. Krumbein and L. L. Sloss. Pp.* 497, *with many line diagrams. W. H. Freeman and Company, San Francisco, Calif.* 1951. £2 2*s.* 6*d. net.*

INDUSTRY

A Glossary of Petroleum Terms. *Prepared by the Nomenclature Sub-Committee of the Institute of Petroleum. Pp.* 16. *The Institute of Petroleum, London.* 1951. 1*s. net.*

Reviews of Petroleum Technology (*Volume* 10). *Hon. Editor, F. H. Garner. Hon. Associate Editor, E. B. Evans. Editor, George Sell. Pp.* 350. *The Institute of Petroleum, London.* 1951. 27*s.* 6*d. post free.*

PHYSICS

Acustica (*Volume I, No.* 1.) *Editor-in-chief, C. W. Kosten. Pp.* 1–48, *with several half-tone and line illustrations. S. Hirzel Verlag. Zürich.* 1951.

Advanced Practical Physics for Students, *by B. L. Worksnop and H. T. Flint. Pp.* 754, *with numerous line diagrams. Methuen and Co. Limited, London.* 1951. 30*s. net.*

The Hardness of Metals, *by D. Tabor. Pp.* 175, *with several line diagrams. Oxford University Press, London.* 1951. 15*s. net.*

Modern Magnetism, *by L. F. Bates. Pp.* 506, *with various line and half-tone diagrams. Cambridge University Press, London.* 1951. 30*s. net.*

Practical Electron Microscopy, *by V. E. Cosslett. Pp.* 299, *with numerous line and half-tone diagrams. Butterworth's Scientific Publications, London.* 1951. 35*s. net.*

Quantum Mechanics of Particles and Wave Fields, *by Arthur March. Pp.* 292. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 44*s. net.*

PSYCHOLOGY

Handbook of Experimental Psychology, *edited by S. S. Stephens. Pp.* 1436, *with numerous line diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 120*s. net.*

ZOOLOGY

Les Diptères de France, Belgique, *by E. Séguy. Two volumes, pp.* 175 *and* 185, *with numerous coloured plates and line drawings. Editions N. Boutec et Cie., Paris.* 1951. 750 *fr. each volume.*

Du Crâne Animal au Crâne Humain, *by A. Delattre. Pp.* 100, *with several line drawings. Masson et Cie., Paris.* 1951. 420 *fr. net.*

Parasitic Animals, *by Geoffrey Lapage. Pp.* 351, *with several half-tone and line illustrations. Cambridge University Press, London.* 1951. 21*s. net.*

Tabulae Biologicae, *Vol. XXII, Oculus. Editors: F. P. Fischer, K. Steindorff, J. S. Friedenwald, J. G. Van Manen, and Arnold Sorsby. Pp.* 284, *with several line diagrams. Dr W. Junk* (*Publishers*), *The Hague.* 1951. £6 11*s.* 9*d.*

Vertebrate Sex Cycles, *by W. S. Bullough. Pp.* 117. *Methuen and Co. Limited, London.* 1951. 6*s. net.*

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